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SEWAGE TREATMENT IN THE UNITED STATES

H. H. Wagenhals, et al

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SEWAGE TREATMENT IN THE UNITED STATES

REPORT ON THE STUDY OF FIFTEEN REPRESENTATIVE SEWAGE TREATMENT PLANTS

BY

H. H. WAGENHALS, E. J. THERIAULT
and H. B. HOMMON

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REPORT ON THE STUDY OF FIFTEEN REPRESENTATIVE SEWAGE TREATMENT PLANTS.

H. H. Wagenhals,[1] E. J. Theriault,[2] and H. B. Hommon.[3]

INTRODUCTION.

The artificial treatment of sewage is a relatively new branch of sanitary science developed chiefly within the last 30 years. Appreciable changes at frequent intervals, not only in the vogue of the various methods available, but also in the views of sanitarians regarding the fundamental principles, purposes and requirements of sewage treatment, are indications that the science is still in a rapid stage of evolution.

The original tendency, following the first full appreciation of the role of sewage in the dissemination of disease, was to demand of sewage treatment an effluent of safe potability. With a realization of the difficulties and expense involved in the production of a "safe" sewage effluent, sentiment has gradually changed, and the present tendency appears to be toward less rigid requirements, more reliance being placed upon the judicious selection of sources and the artificial purification of waters for the protection of public supplies.

Authoritative opinion is still somewhat at variance as to the requirements in sewage treatment, but it is generally conceded that a sewage-treatment plant may be rightly expected to prevent gross nuisance at all times, to protect water purification plants using the receiving body of water from undue loading, and, in general, to maintain the watercourse in such a condition that its use for industrial purposes is not impaired. In certain cases a sewage-treatment plant may be expected to prevent the dangerous pollution of bathing beaches and oyster beds which, in the nature of things, can not be safeguarded by other protective methods.

As in the development of any science, a number of new devices and processes have been brought forward with enthusiastic claims as to their economy and efficiency. As a rule, actual performance has failed to substantiate the claims originally made, although subsequent developments, in some instances, have restored once discarded methods to good standing.

This unsettled status of sewage treatment, due largely to a lack of exact data concerning the relative efficiency of different installations, the frequent failure of plants to achieve promised results, and the rapid advances made in water purification, have all tended to promote a spirit of uncertainty and even skepticism regarding sewage treatment. While this attitude is not common among those technically informed, it has nevertheless found expression among some recognized authorities and is prevalent among public officials upon whom devolves the responsibility for the construction and operation of sewage treatment plants.

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The present study was undertaken in the summer of 1920, by direction of the Surgeon General, the chief purpose in view being the collection of first-hand, uniform, and comparable data upon the efficiency of representative plants in actual routine operation.

In planning the investigation it was realized that relatively few of the plants in the country could be visited. The personnel available for the work was limited, and it was desired to confine the time limits to warm weather, which is the critical time in the operation of any sewage-treatment plant. The plants included in the survey were therefore selected as representing accepted processes or combinations of processes or because of special features on which information was desired.

It would be very easy to cast a cloud over every known method of treatment by reporting on plants which have failed because of faulty design or neglect of operation. As the primary purpose of the work was to secure accurate data on the efficiency of devices and processes of treatment, it was necessary to select plants of competent design and receiving a reasonable amount of care and control. The plants given below are considered to be representative of various devices and processes for the most part properly designed and well operated.

Special features of plants studied.

Alliance	**Contact beds, glass covered sludge beds, intermittent fine filters.**
Canton	**Contact beds, glass covered sludge beds, concentrated sewage.**
Atlanta	**Imhoff tank and trickling filters under southern conditions.**
Fitchburg	**Imhoff tank and trickling filters under northern conditions.**
Lexington	**Imhoff tank and trickling filters, comparatively new installation.**
Columbus	**Imhoff tank and trickling filters, one of the oldest United States plants.**
Rochester (Brighton)	**Imhoff tank and trickling filters, small plant and dilute sewage.**
Baltimore	**Hydrolytic tanks and trickling filters, largest United States plant, fine screens.**
Reading	**Septic tank and trickling filters, one of the oldest United States plants, fine screens.**
Rochester (Irondequoit)	**Riensch-Wurl screens with Imhoff tanks.**
Houston	**Activated sludge, largest plants in routine operation.**
San Marcos	**Activated sludge, small plant with presedimentation and dilute sewage.**
Sherman	**Activated sludge, small plant treating a strong sewage.**

The studies made at the above plants were divided into two parts. The plants were first visited by an engineer who made a physical survey of each plant. This phase of the work was completed between May 24 and September 1, 1920, an average of four days being devoted to each plant. Engineering features of design and operation were entered into and, in addition, information was obtained concerning the population served by the various plants, the total flow of sewage, the cost of construction and operation, and other basic data of importance in estimating the efficiency and economy of the plants. The devices and processes studied included grit-chambers; Riensch-Wurl and other types of screens; plain sedimentation, septic, hydrolytic, and Imhoff tanks; contact, trickling, or intermittent filters; secondary sedimentation; sludge digestion tanks; sludge beds; and activated sludge.

Attention was also given to the study of some special subjects. In particular, wherever it was found that sludge was being used as a fertilizer or soil builder every effort was made to secure first-hand information as to the results obtained. Plant operators interested in this method of ultimate sludge disposal were urged to undertake studies productive of quantitative data upon which a true estimate of the value of sewage sludges as fertilizers or soil builders might be based.

The basis of the engineering survey was a questionnaire, a copy of which may be found in Appendix II. When it was possible to secure complete sets of plans of the plants, much of the questionnaire could be filled out by reference to the plans and the details worked out at a later date in the office. It was necessary, however, to go over all details of the plants in the field at places where the original plans had been modified prior to construction.

Laboratory studies, constituting the second part of the survey, extended from May 27 to December 1, 1920, an average of 16 days being spent at each plant to secure a series of about 12 analyses. The chemist carried with him a complete equipment of the necessary laboratory apparatus and chemical reagents and worked in the local laboratories. Acknowledgment is due to the authorities in charge of the various laboratories for the facilities placed at the chemist's disposal and for the generous loan of sample collectors in several instances. At plants where the personnel was not adequate to take on the extra work, special sample collectors were employed by the Public Health Service. At some of the smaller plants practically all of the operating data, such as flow readings, etc., were collected in this manner.

The laboratory work was rather elaborate, more so than would be advisable for routine plant procedure. Some determinations of admittedly low value were included in order to determine whether they furnished additional information sufficient to justify the labor and time involved in making them. Considerable importance is placed on the fact that the same methods of analysis were used at all plants; in fact, at all but four plants the work was done by the same chemist and at these four plants the work was intrusted to men who had received special training in the methods used. It is believed that the analytical results are unique in this respect.

It was hoped that there might result from these studies a better understanding as to the efficiency of sewage treatment processes and that some progress might be made toward a more or less uniform schedule of methods for making analyses and reporting results. Some of the plants visited are in charge of men who are recognized as the most capable plant operators in the country. From them not only engineering facts were sought, but also opinions and theories regarding their own plants and treatment methods in general. The survey also offered a splendid opportunity for the interchange of methods and ideas concerning sewage analysis. From these informal discussions it appears to be quite generally the case that sewage-plant operators, because of insufficient funds and personnel, are seldom in a position to undertake the original research work which is essential for the proper future development of sewage treatment.

The material embodied in this report is intended to cover the data accumulated during the survey and the conclusions drawn from a study of the data. The first three chapters of the report are devoted to a general discussion of the status of sewage analysis, the sampling technic followed, the interpretative value of the determinations made, and the conclusions drawn as to the best methods of procedure available. A detailed description of the analytical methods is given in Appendix III. The engineering data and the chemical analyses are presented in Chapter IV, each plant being considered separately. The structural features and efficiencies of the various devices and processes are summarized in Chapter V. Detailed descriptions of the plants studied are to be found in Appendix I. During the preparation of the report the descriptions and discussions referring to individual plants have been submitted to the officials in charge of each plant for correction and criticism. By this procedure it is believed that many inaccuracies have been eliminated.

In addition to the authors, Mr. M. J. Blew assisted in these studies from July to September, doing laboratory work.

The success of a survey of this nature depends primarily upon the cooperation of the officials from whom the basic data must be obtained. It is desired to express appreciation of the assistance and courtesies accorded the authors by these officials. It is not possible to include here a complete list of all to whom the authors feel indebted.

To the following, however, it is felt that personal acknowledgment is due:

At Alliance, Ohio: J. H. McConnel, director of public service; Homer Anderson, city engineer; A. E. Hesse, chemist; I. W. Irwin, plant foreman.

At Atlanta, Ga.: H. L. Collier, chief of construction; C. C. Hommon, chemist in charge of sewage treatment.

At Baltimore, Md.: Milton J. Ruark, division engineer of sewers; C. E. Keefer, sanitary engineering assistant; J. W. Holden, superintendent of sewage-disposal works; T. C. Schaetzle, principal sanitary chemist.

At Canton, Ohio: W. E. Sarver, city engineer; A. E. Hesse, chemist; F. Eversole, sewage plant foreman.

At Columbus, Ohio: C. B. Hoover, chemist in charge; C. D. McGuire, assistant chemist.

At Fitchburg, Mass.: D. A. Hartwell, commissioner of public works; H. B. Allen, chemist in charge at disposal plant.

At Houston, Tex.: J. C. McVea, city engineer; G. L. Fugate, principal assistant engineer; W. R. Tidwell, chemist at sewage plants; Bruce Meyer, superintendent north side treatment plant; W. E. Green, superintendent south side treatment plant; V. R. Lang, foreman sludge drying plant.

At Lexington, Ky.: W. H. McCorkle, commissioner of public works and vice mayor; J. W. Guyn, city engineer; H. D. Spears, chemist; M. E. Crawley, superintendent sewage disposal plants.

At Reading, Pa.: W. B. Yeager, commissioner of public works; E. B. Ulrich, city engineer; P. Merkle, chemist sewage-treatment plant; S. U. Lafferty, foreman at sewage plant.

At Rochester, N. Y.: C. A. Poole, city engineer; J. F. Skinner, principal assistant engineer; N. A. Brown, special assistant engineer; B. G. Dewitt, superintendent Irondequoit plant.

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The technical press has been freely used and much material obtained from it as well as from the standard books on sewage treatment. Every effort has been made to credit in the body of the report the authors of articles from which material has been taken.

CHAPTER I.

ANALYTICAL METHODS.

GENERAL CONSIDERATIONS.

It was realized at the start and amply confirmed during the survey that any comparison of the efficiency of the various methods of sewage treatment based on published analyses to be found in annual reports or in the technical press would be entirely misleading. Real comparisons of the performance of some of the larger plants from published data are, in fact, virtually impossible due to a lack of uniformity in the choice of the analyses made or in the methods of procedure where similar tests are conducted. Too frequently the determinations are chosen with regard to local precedents or are carried out in the light of individual preferences.

Once a routine has been established a strong disinclination toward standardization involving radical changes is quite excusable. At some plants the routine analyses cover a period of years dating from the time the plant was first put into operation. Any change in methods of analysis would render comparisons impossible within the plant itself, a disadvantage which must be weighed against the advantages of a modified procedure which would permit comparisons with results obtained in other places.

The general acceptance of the standard methods of the American Public Health Association has been a long step forward in the standardization of laboratory procedures, although considerable differences are possible even in laboratories by which standard methods are fully adopted. Nitrates, for example, may be determined by one of two methods, the reduction method or the phenoldisulfonic acid method; the biochemical oxygen demand may be determined by three different methods, viz, the relative stability method, the nitrate method, and the excess oxygen method; ammonia nitrogen may be determined by distillation or by direct nesslerization. It is by no means established that these different methods give equivalent results. In the case of oxygen demand tests, even if the results obtained by the several methods available were concordant, there would still be considerable latitude in the choice of incubation temperatures or even in the choice of a period of incubation. The greatest difficulty arises, however, not in the details of the procedures themselves but in the choice of the tests to be made. At one plant, nitrification may be taken as an index of the efficiency of a trickling filter; another plant with a similar installation may consider that the permanganate oxygen consumed or the relative stability is the best index.

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In certain sections where sewage-treatment plants are under competent State supervision the analyses to be made are specified. Unfortunately no agreement exists between the officials of different States as to what constitute suitable laboratory procedures. The determination of the various forms of nitrogen, for example, may be stressed by some and discarded altogether by others.

In the absence, therefore, of a generally accepted procedure, it is apparent that in any study of sewage treatment having for its purpose the comparison of the various methods in use in widely scattered sections of the country, the collection of analytical data derived under uniform conditions would be a primary requisite. No special claim is made for originality, or unusual refinements in the analyses submitted in this report. Their chief virtue lies in the fact that they make possible a direct comparison of the various plants visited, without qualification as to differences of procedure.

CHAPTER II.

SAMPLING TECHNIC.

NUMBER OF SAMPLES COLLECTED.

The number of samples to be collected was a question which received considerable attention. It was decided that the sampling period should cover at least 10 days if the results obtained were to be relied upon as being properly representative. Actually, this lower limit was exceeded in most cases.

METHOD OF SAMPLING.

The method followed was to collect hourly samples of 150 c. c. over a full 24-hour period. These samples were composited, giving a volume of 3,600 c. c. for analysis. Sample collectors were instructed to dip below the surface of the sewage and to include all suspended matter caught in the sample. Glass-stoppered, wide-mouthed bottles provided with wire handles were used for the sampling. When completely filled the stoppers were set in place, thereby giving a constant volume at each sampling period. One-gallon bottles were used for storing the composited samples.

Due to limitations of time and personnel it was necessary to collect Sunday samples. In the table given below one Sunday sample from each place is compared with the six samples immediately following or preceding it.

TABLE NO. 1.—*A comparison of analyses of Sunday and week-day raw sewages.*

[The values given are corresponding sums from 14 plants. Original results in terms p. p. m. and c. c. per liter for settleable solids.]

	Suspended matter.	Settleable solids.	Oxygen consumed.	Alkalinity.	Ether soluble matter.	Chlorides.	Oxygen demand 5-day.	Dissolved oxygen.
Sundays only........	2,096	32.2	598	3,006	631	1,159	1,336	21.6
Week days only......	2,663	38.7	611	3,026	832	1,281	1,691	11.7
Week days and Sundays...............	2,542	37.9	610	3,023	803	1,264	1,629	13.1

The suspended matter in the Sunday samples is about 20 per cent lower than in the samples collected on week days only. Excepting the dissolved oxygen, the same holds true for the other determinations. The values derived from a consideration of week-day results only are not materially different from those in which a Sunday sample was included. The inference is that the omission of samples for a 24-hour period each week would not materially affect the weekly average. Possibly the omission of two or three more days would still give a perfectly reliable average value.

Other methods of sampling practiced at various places are as follows:

1. Sampling according to flow is practiced at Fitchburg, Mass., and is, logically, the correct procedure; the use of direct-reading flow-measuring devices is implied.

This method has the advantage that the analytical results are weighted. Sampling errors, however, are largely counterbalancing where constant volume samples are taken. This is brought out in the following table prepared from data contained in the report on tests at the sewage-testing station at Cleveland, 1914. The values given are monthly averages.

TABLE No. 2.—*Agreement between samples proportioned to flow and those where a constant amount of sample was taken at each sampling period.*

[Results in parts per million.]

Samples.	Month.	Oxygen consumed.	Suspended matter.			Organic nitrogen.	Free ammonia.	Chlorine.	Alkalinity.	Iron (Fe).
			Total.	Volatile.	Fixed.					
A	April	45	195	88	107	7.2	12	286	155	14
B	April	47	204	98	106	7.3	13	284	157	15
A	May	50	252	114	138					
B	May	52	269	116	153					

A, samples proportioned to flow. B, a constant volume of sample taken.

2. A single sample is taken at a time of the day found by experiment to represent the average strength of the sewage. This method is followed at Baltimore. It has the advantage that sample collectors are practically eliminated, but it can be used only where the composition of the sewage is nearly constant.

PRESERVATION OF SAMPLES.

No attempt was made to preserve the samples other than by refrigeration. The hourly samples were transferred as soon as possible after collection to a 1-gallon stoppered bottle kept on ice or in an ice box. Excepting the dissolved oxygen content, the changes which take place in the composition of an iced sample within 24 hours are probably not very great.

At some plants chloroform is used as a preservative; acids are also used for the same purpose. If biochemical oxygen demand or putrescibility tests are to be made, sterilization, evidently, is not permissible. In interpreting the results of analyses it should be borne in mind that bacterial activity is only slowed down and not completely arrested by refrigeration. Chloroform alone is of doubtful value as a preservative; acidification is effective. Chloroform and refrigeration together are also effective.

COMPETENCE OF THE SAMPLES.

It is believed that the results obtained are fairly representative of average summer conditions at the plants visited; in fact, with the exception of Atlanta where heavy rains were encountered, the results for any given plant vary but little from day to day. Sudden variations are generally connected with the unloading of a tank or a heavy rain. At all plants, with possibly one or two exceptions, it was agreed by the local officials that the analyses were fairly representative, and, wherever the methods in use by the local chemists were at all comparable, the results were found to agree quite closely.

The following table gives data collected from various sources to establish this point of agreement:

TABLE No. 3.—*Agreement between the values obtained by local chemists and those obtained during the survey.*

[Results in parts per million.]

Plant.	Suspended matter.				Source from which local values were derived.
	Raw sewage.		Final effluent.		
	Local value.	Survey value.	Local value.	Survey value.	
Alliance	153	152	16	17	Average from May to October, 1919, from annual report.
Atlanta (Intrench)	140	106	....	....	From paper read at twenty-third annual Convention of Am. Soc. Mun. Imp., by C. C. Hommon.
Atlanta (Peachtree)	145	226	....	....	Do.
Baltimore	185	159	40	41	Average from April to October, 1912 to 1920, from Eng. News-Record of July 21, 1921.
Columbus	219	206	78	81	Average from May to October, 1920, from annual report.
Fitchburg	346	297	35	42	Average from May to October, 1919, from annual report.
Lexington	208	166	34	48	Average of 3 analyses from May to July, 1919.
Rochester (Brighton)	121	101	12	10	Average from April to October, 1918, from annual report.
Reading	104	145	30	31	Do.
Sum	1,621	1,558	245	270	
Average	180	173	27	30	

In the above table the suspended-matter determinations made during the survey are compared with values derived by local chemists. The agreement in the case of the final effluents is very good and even with raw sewage a good general agreement is obtained. Unfortunately it was found impossible to extend this table, since the suspended-matter determination is about the only test in general use on which practical agreement obtains as to the method of procedure.

CHAPTER III.

INTERPRETATIVE VALUE OF THE VARIOUS DETERMINATIONS MADE DURING THE SURVEY.

Operative, laboratory, and administrative work at sewage plants is generally in excess of the available personnel. The selection of suitable laboratory tests and the elimination of timeworn or tedious determinations of doubtful value should receive the careful attention of the plant operator.

The laboratory schedule followed during the survey is given below. It included most of the tests that are commonly made on sewage, a notable exception being the total nitrogen. This determination could not very well be included due to the bulky nature of the apparatus required. The resulting list is a cumbersome one, and while capable of furnishing comparative data of great value is obviously not recommended for routine procedure.

1. Alkalinity.
2. Chlorides.
3. Nitrogen as nitrate.
4. Relative stability.
5. Settleable solids.
6. Suspended matter.
7. Ammonia nitrogen.
8. Ether soluble matter (fats).
9. Oxygen consumed.
10. Dissolved oxygen.
11. Biochemical oxygen demand.
12. Complete sludge analysis.

In the following pages the interrelation of the above determinations and their limitations when applied to sewage analysis will be briefly discussed. The importance of the biochemical oxygen demand test will be emphasized by frequent reference to this value. The analytical results presented to illustrate the text are taken from tables given in Chapter IV, and detailed descriptions of the analytical methods used are given in an appendix to this report.

1. ALKALINITY.

For a raw sewage this value is determined largely by the alkalinity of the water supply, the presence of industrial wastes, and, especially, by the indicator chosen for the test. No particular significance is attached to the alkalinity of the raw sewage excepting, of course, where industrial wastes are present in unusual quantities. More significant are the changes in the value of the alkalinity as the sewage passes through a plant.

TABLE No. 4.—*Changes in the alkalinity of a sewage on passing through Imhoff, septic, or hydrolytic tanks.*

[Results in parts per million.]

Source.	Alliance.	Atlanta (Intrench).	Atlanta (Peachtree).	Baltimore.	Canton.	Columbus.	Fitchburg.	Lexington.	Rochester (Irondequoit).	Rochester (Brighton)	Reading.
Effluent	194	82	69	144	343	219	99	194	190	189	177
Influent	184	77	68	136	342	211	97	196	175	178	164
Increase	10	5	1	8	1	8	2	−2	15	11	13

Excepting at Lexington, where a slight decrease was noted, all plants indicate an increase in alkalinity, although the increase is so small that it can be ascribed, largely if not entirely, to experimental errors. At places like Alliance, Reading, and Rochester, where increases of 10 to 15 parts per million were noted, the change may possibly be connected with a slight unloading of material from the sludge chamber where, as shown in the following table, the alkalinity reaches a very high figure.

TABLE No. 5.—*Comparison of the alkalinity of Imhoff sludge filtrates with that of the corresponding raw sewage.*

[Results in parts per million.]

Source.	Alliance.	Atlanta (Peachtree).	Baltimore.	Columbus.	Fitchburg.	Lexington.	Rochester (Brighton).	Rochester (Irondequoit).
Sludge filtrate	880	520	380	890	980	1,150	640	560
Raw sewage	184	68	138	211	97	196	178	175
Increase	696	452	242	679	883	954	462	385

The alkalinity of the filtrate from freshly drawn sludge was determined at most plants visited. The results are summarized in the above table and compared with the alkalinity of the corresponding raw sewage.

It is noted that the differences shown in Table No. 5 are too large to be attributed to experimental errors. The maximum increase was at Lexington and is in the neighborhood of 1,000 parts per million. From the analyses of the sludge ash, as given later in Table No. 63, it can be calculated that the $CaCO_3$ content of the wet sludges varies from 2,000 to over 5,000 parts per million. Much of this $CaCO_3$ is, of course, not in solution, but it is not inconceivable that the sludge filtrate contains as much as 1,000 parts per million, especially when consideration is given to the fact that the decomposition of the sludge gives rise to large amounts of carbon dioxide. Also it must be remembered that the sludge represents, roughly at least, that part of the sewage which is in coarse suspension, i. e., the settleable matter, and that the inorganic matter content of this portion is presumably higher than that of the liquid part of the sewage. The conditions are, therefore, favorable for the concentration of inorganic salts in the sludge and for the solution of the calcium carbonate in the surrounding liquid.

The foregoing discussion has been presented entirely from the standpoint of the classical methods of analysis and interpretation, and without reference to the limitations of the titrimetric method for the determination of alkalinity. That this simple treatment is by no means satisfactory is fully recognized.

The end-point reached with an indicator, such as methyl orange in the presence of weak organic acids, which can be assumed to be present in sludge filtrates, is by no means definite. The color changes observed are very gradual, and the tendency is to add too much acid. The end-point is also rendered uncertain by the presence of certain substances, such as phosphates and proteins, which act as buffers, tending to oppose any sharp change in the color of the indicator. Under these conditions end points are indeterminate and possibly meaningless. Instead of representing $CaCO_3$, the alkalinity results may merely be a measure of how well the sludge filtrate is buffered. Unfortunately, data on the hydrogen ion concentration of sludge filtrates are not available and some practical difficulties will have to be solved before such determinations can be made.

The decrease in the alkalinity of a sewage on passing through a trickling filter, a contact bed, or an activated sludge plant is shown in the following table. The nitrates and the 5-day oxygen demand of the effluents are also included for comparison.

TABLE No. 6.—*Changes in the alkalinity of a sewage on passing through an oxidizing device.*

[Results in parts per million.]

Source.	Trickling filters.								Contact beds.		Activated sludge.			
	Fitchburg.	Baltimore.	Reading.	Rochester (Brighton).	Lexington.	Atlanta (Intrench.).	Atlanta (Peachtree).	Columbus.	Alliance.	Canton.	Houston (south side).	Houston (north side).	San Marcos.	Sherman.
Alkalinity:														
Influent	99	144	177	189	194	82	69	219	194	343	304	270	311	515
Effluent	8	63	105	131	152	48	35	192	167	354	220	198	238	416
Decrease	91	81	72	58	42	34	34	27	27	−11	84	72	73	−1
Nitrogen as nitrates	5.2	3.3	4.4	2.8	.....	3.0	2.0	0.6	2.8	0.3	6.0	4.6	8.8	1.2
5-day oxygen demand	20	14	20	7.1	1	4.2	3.9	49	20	27	7.4	11	16	40

Whatever significance may be attached to alkalinity results, the changes shown above are not subject to the same sources of error as in the case of the determinations made on sludge filtrates. In the sludge filtrates the presence of weak organic acids and of buffers might account for a good part of the indicated change in alkalinity, but in the effluent of an oxidizing device the organic matter content has been greatly reduced and the end-points reached are very sharply defined. The significance of these results is emphasized by comparing the decrease in alkalinity with the degree of nitrification and the oxygen demand of the effluents at plants where the raw sewages are somewhat comparable. At Fitchburg where a maximum decrease of 91 parts per million was observed, a maximum of nitrification, in a trickling filter effluent, 5.2 parts per million of nitrogen as nitrates, and a low oxygen demand were also found. At Columbus where the raw sewage is somewhat comparable to that of Fitchburg the smallest decrease in alkalinity, 27 parts per million, was accompanied by the lowest nitrification, 0.6 parts per million, and the highest oxygen demand, 49 parts per million, observed in any filter effluent. It might be objected that at Fitchburg the filtering material is composed of trap rock while at Columbus limestone, which might have an effect on the alkalinity, is used. The same general tendency is noted, however, if Lexington be substituted for Fitchburg. While nitrate figures are not available for Lexington, the oxygen demand results are 49 and 16, and the decrease in alkalinity 27 and 42, respectively, for Columbus and Lexington.

The same result is noted if the results from two contact beds are compared. Alliance shows a decrease in alkalinity of 27 parts per million and Canton shows a slight increase or practically no change; the effluent at Alliance is much more stable than that at Canton.

It does not appear that this relation between alkalinity changes and oxidation is limited to devices involving the use of a solid filter material. Large decreases in alkalinity were found at the Houston and San Marcos activated sludge plants, and these plants produce very highly stabilized effluents. At Sherman a condition of practically no change in the alkalinity of the sewage in passing through the plant is correlated with an effluent of much poorer quality.

The Brighton plant at Rochester gave an effluent of very high quality and showed much smaller decrease in alkalinity than the Fitchburg or Baltimore plants, but the raw sewage at Brighton is so much weaker than the raw sewages at Baltimore and Fitchburg that a comparison of these plants is not justified.

If the values given in Table No. 6 are considered along with other criteria on which the efficiency of a plant may be estimated, it appears that a sizable reduction in the alkalinity of the sewage as it passes through an oxidizing device is correlated with the efficient behavior of the plant or, roughly, that the reduction in alkalinity is a measure of the biological activity within the oxidizing device.

This conclusion, admittedly, would rest on a somewhat firmer basis if, instead of the reduction in alkalinity, we were to consider the displacement in the pH value of the sewage due to its passage through an oxidizing device. Data on this displacement in the pH value are not available except, by inference, at Fitchburg, where the pH value was such that the effluent of the trickling filters was practically neutral to methyl orange. The indicated pH value in this case is in the neighborhood of 4.0. The pH value of raw sewage is in the neighborhood of 8.0. If instead of methyl orange an indicator, such as methyl red, with a color change occurring above a pH value of 5, had been chosen, the Fitchburg effluent would have reacted acid, and the influent alkaline.

In the absence of more complete analytical data it would be hazardous to present any definite conclusions. It would seem probable, however, that the displacement in the pH value of the sewage on passing through an oxidizing device, might be a measure of the amount of biological activity that has been expended on the purification of the sewage, or otherwise stated, a measure of the amount of organic matter that has been worked over by the bacteria. It would be expected that, other things being equal, the greatest displacement should occur where the amount of organic matter oxidized was the greatest.

From the tables presented above and the accompanying discussion it is apparent that the alkalinity of a sewage is subject to decided changes as the sewage passes through a treatment plant. These changes, however, are not readily interpretable due to the uncertain significance of the alkalinity determination. It would seem that the substitution of the readily applied colorimetric determination of the hydrogen ion concentration for the old titrimetric alkalinity determination would furnish information of more definite character and of great potential value in the operation of a sewage-treatment plant. Since this determination requires no greater time or skill, and does not involve the use of more expensive apparatus than that required for the titrimetric determination of alkalinity, it seems advisable to replace the alkalinity determination by the determination of the hydrogen ion concentration. This has already been done by the bacteriologists in the preparation of their culture media, where it has been shown that it is the hydrogen ion concentration of a medium rather than its alkalinity which determines, largely, its suitability for the growth of bacteria. If bacterial activity can be favored by an adjustment of the pH value of a medium, it would seem that a study of sewage purification from this angle of approach would offer a most promising field of investigation.

It would be highly desirable, for instance, to secure data on the pH value of well-digested sludges with the object of determining whether such values can not be used to indicate the fitness of sludge for withdrawal from a tank.

The foaming of Imhoff tanks is another phenomenon apparently correlated with a change in the character of biological activity, for which no satisfactory explanation or method of control is as yet available. Here again a knowledge of the hydrogen ion concentration involved might offer a mode of attack. The slight increase in the alkalinity of a tank effluent is possibly paralleled by a similar change in the hydrogen ion concentration, and might give valuable information as to the behavior of the Imhoff tank.

The decided decrease in the alkalinity of a sewage on passing through an oxidizing device is undoubtedly connected with a change in the hydrogen ion equilibrium. Here too, hydrogen ion determinations might give a measure of the biological activity.

At plants where acid wastes are encountered, adjustment of the sewage to a normal pH value, say 8.0, would seem to be a more rational method than an adjustment to a given alkalinity. Likewise, in experiments on sludge digestion, the adjustment of the sludge to a pH value most favorable to the special types of bacteria involved would seem a logical method of procedure. Certainly in experiments on the chemical precipitation of sewage the pH value is an important factor, especially if it is considered that, for many substances, an optimum pH value exists above or below which precipitation is imperfect.

2. CHLORIDES.

The chloride content of a strictly domestic sewage should vary somewhat with the concentration of the polluting material and with the character and amount of the industrial waste contribution. Since the chloride content does not change in passing through the plant, the determination is of potential value only in estimating the strength of a raw sewage. Its usefulness for this purpose is quite limited, however, and, on the whole, it can be safely stated that the determination does not give data of sufficient value to warrant its inclusion in a routine schedule of analyses.

In Table No. 7, the chloride results obtained during the survey have been arranged in the descending order of their magnitude, and the corresponding 5-day oxygen demand results have been placed below.

TABLE No. 7.—*Comparison of the chloride content of raw sewage with its 5-day oxygen demand.*

[Results in parts per million.]

Determination.	Houston (north side).	Sherman.	Reading.	Columbus.	Houston (south side).	Atlanta (Intrench.).	Lexington.	Atlanta (Peachtree).	Baltimore.	San Marcos.	Rochester (Irondequoit).	Canton.	Fitchburg.	Alliance.	Rochester (Brighton).
Chlorides	136	129	120	113	101	93	89	86	86	83	82	79	70	47	45
5-day oxygen demand	115	202	118	190	112	63	144	52	120	67	104	213	155	93	67
Ratio	0.9	1.6	1.0	1.7	1.1	0.7	1.6	0.6	1.4	0.8	1.3	2.7	2.2	2.0	1.5

Any agreement between the chloride content and the oxygen demand would be indicated by a rather constant value for the ratio of the two. By inspection it is apparent that the relation is a very loose one. In the above table, the chloride results are uncorrected for the chloride content of the water supply, and at some places an appreciable error would perhaps be introduced by this omission. As a rule, however, the chloride content of a water supply is low compared with sewage. At Houston, Atlanta, and Rochester, where two plants were studied, the chloride content appears to vary somewhat directly with the oxygen demand. Without corrections for the chloride contribution of the industrial wastes, the strength of a sewage as indicated by its chloride content would be entirely misleading.

In Table No. 8 the contribution of chlorine as chloride at the plants visited has been computed in terms of grams per capita per day. The plants are arranged in the ascending order of this quantity.

TABLE No. 8.—*Contribution of chlorine as chlorides in grams per capita per day.*

[Results in parts per million.]

	Canton.	Sherman.	Rochester (Brighton).	Alliance.	Fitchburg.	San Marcos.	Houston (south side).	Lexington.	Baltimore.	Houston (north side).	Columbus.	Rochester (Irondequoit).	Reading.	Atlanta (Peachtree).	Atlanta (Intrench).	Average value.
Chlorides	79	129	45	47	70	83	101	89	86	136	113	82	120	86	93	....
Gallons per capita per day	64	44	128	131	88	80	75	89	108	75	94	137	101	160	167	....
Grams per capita per day	19	21	22	23	23	25	29	30	35	39	40	43	46	52	59	34

In Table No. 8, the chloride content of the water supply has been neglected; the chlorine determinations are those made during the survey; and the total flows are average flows under dry weather conditions.

The average contribution at the plants studied was 34 grams per capita per day with an average deviation of about ±10. grams from this value.

If the per capita per day contribution of chlorine as chlorides is taken as 34 grams and the chloride content of the sewage is known, the gallons of sewage per capita per day can be computed. The probable error involved in such a computation, however, would be very great.

3. NITROGEN AS NITRATES.

Nitrification is a time-honored and widely used criterion of the quality of an effluent. For the determination of nitrates in sewage effluents it is necessary to use the reduction method, since, in the presence of chlorides in amounts above 10 or 15 parts per million, the phenol-disulphonic acid method is entirely unreliable. The reduction method, while capable of giving accurate results, is time-consuming and, in many respects, unwieldy. It is to be borne in mind that the quantity reported as nitrates by this method includes the nitrites, unless the nitrite content has been determined on a separate sample and deducted. The inclusion of the nitrites, however, introduces no serious error, since the nitrite content is usually very low and the significance of the two forms of nitrogen is much the same. The term, "reducible nitrogen," is probably more descriptive of the value in question.

While the degree of nitrification can be taken as a good index in judging the efficiency of a particular plant, it is not a value which can be used for a comparison of various methods of treatment or for estimating the relative efficiency of different plants, unless it is assumed that the nitrogen content of all sewages is the same, an assumption which is surely not warranted.

Other things being equal, the amount of nitrates present in an effluent should be somewhat proportional to the amount of nitrifiable material present. If it is assumed that the nitrogen content of sewage is roughly proportional to its strength or to the concentration of polluting material in the sewage, it would appear that a weak sewage, although very highly purified, could not be expected to show as high a nitrate content as a much stronger sewage which has reached an equally high degree of purification. This appears to be the condition at some of the plants visited. For example, if the nitrate content of 6.1 parts per million in the final effluent from the Fitchburg plant is compared with the nitrate content of only 2.9

parts per million in the final effluent from the Rochester plant, it might be inferred, using the extent of nitrification as a basis of comparison, that the Fitchburg plant was operating much more efficiently than the Rochester plant. The raw sewage at Fitchburg, however, is more than twice as strong as that at Rochester and, if the above reasoning is correct, the nitrate content at Fitchburg should be twice as high as at the Rochester plant. These two plants have been chosen for comparison because it is believed that each one is turning out about as good an effluent as is possible with the methods of treatment used.

In the interpretation of nitrate results, therefore, the strength of the raw sewage should be considered, and allowance made for the fact that nitrification, measured in absolute units, is not a suitable test for use in comparing the relative efficiency of various plants unless complete information concerning the various forms of nitrogen is available. It is very doubtful whether the additional information gained would justify the time and labor involved.

4. Relative Stability.

A decided advantage of this method is its simplicity, which makes it available for use by a nontechnical plant foreman in judging the quality of an effluent. In general, if an undiluted effluent holds up for five days at ordinary temperatures, it can be stated that the effluent is sufficiently stabilized and will not cause gross nuisance.

During the survey relative stability tests were made with tests for the biochemical oxygen demand by the excess oxygen method. The results obtained by the two methods are fairly concordant, due allowances being made for the limitations of the relative stability test. The time required for the decolorization of methylene blue is not a quantity that can be determined very accurately, since the color change involved is by no means always sharply defined. Unmistakable colorations will persist for days after the bulk of the color has disappeared, and this can hardly be ascribed to reaeration when the color is uniformly distributed throughout a tightly stoppered bottle. Whatever the explanation may be, the frequent absence of a sharp end-point affects the accuracy of the relative stability method somewhat seriously, and makes it inadvisable to use the relative stability determination where more than roughly quantitative information is desired. The degree of concordance between the two methods will be illustrated by a few examples.

At the Houston north side plant the effluent samples incubated in the presence of methylene blue held up for 10 days or over and the 5-day oxygen demand of the effluent was 11 parts per million; at Fitchburg the samples held up for 10 days also, but the oxygen demand was 21. At the Rochester Brighton plant the samples held up for over 5 days and the oxygen demand of the effluent was 5.2 parts per million, while at Lexington the relative stability samples held up for over 5 days also, but the oxygen demand of the effluent was 16 parts per millon. At Canton, Sherman, and Columbus, however, the samples incubated in the presence of methylene blue held up for less than 5 days and the oxygen demand values were 37, 40, and 49, respectively.

From the above illustrations, and from tests made at other plants, it appears that whenever the 5-day oxygen demand is below 20 parts per million the relative stability test will show that the effluents are all about alike, i. e., the samples will not decolorize within 5 or 10 days. If the oxygen demand is in the neighborhood of 40 or 50 parts per million, this fact will be indicated by the decolorization of methylene blue after less than 5 days of incubation. A choice between the two methods of estimating the quality of an effluent is determined by the degree of accuracy desired, or the use to which the information is to be put.

Considering the two activated sludge plants at Houston, it would be impossible to determine by inspection or by the physical appearance of the effluents which plant was giving the better effluent, the effluents at both of these plants being very highly purified. The structural features of these plants are almost identical, the main difference being the number of units provided. The methods of operation, however, differ in some respects, e. g., at one plant sludge removal from the sedimentation tank is continuous, while at the other the sludge is removed intermittently. The relative stability test indicates that both plants are performing equally well, all samples holding up for at least 10 days. The 5-day oxygen demand of the north side plant, however, was 11 parts per million, while that of the south side plant was only 7.4 parts per million. These results are in accordance with other chemical data from which the character of the two effluents might be judged, e. g., the degree of nitrification, the dissolved oxygen content, and the character of the sludge.

The relative stability test can also be used for estimating the strength of a raw sewage. The dilutions involved and the necessary determinations of the initial available oxygen content, however, require the services of a chemist, in which case the strength of the sewage is best determined by the oxygen demand test with a much higher degree of accuracy and, possibly, a lesser expenditure of time.

5. SETTLEABLE SOLIDS.

The settleable solids represent the coarser portion of the suspended matter or, better, that portion of the suspended matter which settles out readily. This quantity may be determined by noting the volume of the solids which settle out in a given time from a known volume of sewage contained in a glass vessel of suitable shape. The results are expressed in cubic centimeters of solids that settle out of a given volume of sewage within a specified time. The settleable solids may also be determined by weight if the suspended matter in the raw sewage is known and the suspended matter in the supernatant fluid of the raw sewage is determined after allowing the solids to settle for a definite time.

The following table has been prepared to bring out the relationship between these two quantities.

Table No. 9.—*Comparison of the settleable solids by volume with the settleable solids by weight in raw sewage.*

Settleable solids.	Sherman.	Canton.	Baltimore.	Rochester (Brighton).	Reading.	San Marcos.	Columbus.	Alliance.	Houston (north side).	Rochester (Irondequoit).	Fitchburg.	Houston (south side).
Cubic centimeter per liter...	5.0	5.3	29	2.0	2.0	2.2	3.1	2.0	25	2.1	2.7	2.0
Parts per million...........	179	190	114	83	90	100	146	115	154	139	241	178
Ratio......................	36	36	39	42	45	45	47	58	62	66	89	89

The agreement between the ratios given in the above table is a rough measure of the correspondence between the settleable solids by volume and the settleable solids by weight. It is not to be expected that the agreement would be any too close, since the determination of settleable solids is subject to many sources of error. The variation in the value of the ratio is to be connected, to some extent at least, with the character of the settleable solids, and the deviation from the average ratio is a rough measure of the state of disintegration of the settleable solids. The effect of the degree of disintegration on the settleable solids by volume is well illustrated at the Rochester Irondequoit plant, where the settleable solids by volume in the raw sewage before and after passing through a Riensch-Wurl screen were 2.1 and 2.3 c. c. per liter respectively. In this case the apparent increase was very evidently due to a change in the character of the suspended matter, the settled solids in the Riensch-Wurl screen effluent being visibly more highly disaggregated than those in the raw sewage. In the case of Imhoff and septic tank effluents the settleable solids by volume, as a rule, are hardly measurable with any degree of accuracy.

In the following table a comparison is made between the settleable solids by volume and the total suspended matter in the effluent of the sedimentation tanks studied.

TABLE No. 10—*Comparison of the settleable solids by volume with the total suspended matter in tank effluents.*

Solids.	Rochester (Brighton).	Fitchburg.	Lexington.	Atlanta (Intrench).	Alliance.	Atlanta (Peachtree).	Columbus.	Reading.	Canton.	Baltimore.	Rochester (Irondequoit).
Settleable [1]	Tr.	Tr.	Tr.	0.6	Tr.	Tr.	Tr.	Tr.	0.3	0.6	0.7
Suspended [2]	40	63	67	67	69	69	79	85	93	107	119

[1] Tr. indicates less than 0.1 c. c. per liter.

[2] Results in parts per million.

In general, it is only when the total suspended matter reaches a value of about 100 parts per million that the settleable solids are greater than a trace, i. e., 0.1 c. c. per liter. The applicability of the settleable solids by volume determination to tank effluent is, therefore, restricted to the extreme case. While it is very useful for this purpose, it can not be used to differentiate a very good from a fair effluent. With a raw sewage the test is universally applicable, since a measurable amount of settleable solids is always present. In this case the determination can furnish information of value in preliminary studies, such as are made at sewage-testing stations, where the volume of the settleable solids is a factor in the design of a tank.

The foregoing remarks are not applicable to activated-sludge plants. Here the volume of the sludge is an important factor in the control of plant operation and the determination of the volume of the settled sludge is an important test. The volume occupied by the same weight of sludge is greatly influenced by the settling period chosen and the character of the sludge. Since activated sludge has a tendency to decompose very rapidly, the settling period can hardly be extended much over a half hour, and for routine plant operation, where the volume of the sludge in the system is to be maintained within a favorable range, the time of settling may be even shorter. The following table illustrates the change in volume with respect to time:

TABLE No. 11.—*Volume of settled activated sludge after various intervals of time.*

Nature of sludge.	Time in minutes.								Type of vessel.
	0	2	5	10	15	30	60	Overnight.	
Tank effluent	1,000	700	420	325	280	230	180	....	Imhoff cone.
Returned sludge	1,000	....	950	910	890	820	720	425	Do.
Do.	1,000	990	980	970	960	900	750	350	Cylinder.

On standing overnight the sludge from the tank effluent had risen to the top of the vessel while the returned sludge occupied a volume of 425 c. c. in the Imhoff cone and 380 c. c. in the 1,000 c. c. cylinder. It is evident that the volume of the sludge changes very rapidly with the time. Other tests of similar nature indicate that the volume is also influenced by the shape of the vessel used. Cylindrical vessels, such as 1,000 c. c. graduates, appear to be the most satisfactory.

In interpreting this test as applied to activated sludge it is to be borne in mind that the volume occupied by the settled sludge does not bear a constant relation to the actual weight of sludge present unless the character of the sludge remains the same. If sludge is suspected of having "gone bad" its physical appearance, its odor, or its color are probably better indications than the volume it occupies on settling. These facts are brought out in the following table:

TABLE No. 12.—*Comparison of the volume occupied by settled activated sludge from aeration tank effluents with its total suspended matter content.*

"VERY GOOD" SLUDGE.

Plant.	Volume in c. c. per liter.		Suspended matter in parts per million.	Ratio 30 minutes.	Ratio 15 minutes.
	After 15 minutes settling.	After 30 minutes settling.			
Houston (south side)	260	240	10,500	44	44
Do.	250	225	8,990	40	36

"GOOD" SLUDGE.

Plant.	After 15 minutes settling.	After 30 minutes settling.	Suspended matter in parts per million.	Ratio 30 minutes.	Ratio 15 minutes.
Houston (north side)	380	300	6,750	22	18
Do.	280	240	4,950	21	18
Do.	250	180	4,220	23	17
Do.	200	180	4,270	23	21
Do.	200	160	4,020	25	20
Do.	160	150	3,200	21	20

"FAIR" SLUDGE.

Plant.	After 15 minutes settling.	After 30 minutes settling.	Suspended matter in parts per million.	Ratio 30 minutes.	Ratio 15 minutes.
San Marcos	380	300	3,640	12	9.6
Do.	280	230	2,000	8.7	7.1

"BAD" SLUDGE.

Plant.	After 15 minutes settling.	After 30 minutes settling.	Suspended matter in parts per million.	Ratio 30 minutes.	Ratio 15 minutes.
Sherman	490	380	2,070	5.5	4.2
Do.	500	360	1,960	5.4	3.9
Do.	500	350	1,700	4.9	3.4
Do.	500	380	1,540	4.1	3.0

It is apparent from this table that the conclusions reached at different plants would differ widely if the volume of the sludge were taken as an index of the amount of sludge present. At Sherman where the greatest volume of sludge was obtained the actual weight of the sludge was the least. At the Houston south side plant the volume of sludge was very low but the actual weight of the sludge was the highest observed, reaching a value of around 10,000 parts per million, or about 1 per cent. If instead of comparing different plants, however, results obtained at any particular plant are examined, it appears that the volume bears a definite relation to the actual weight of sludge present. This is indicated by a fairly constant value at any given plant for the ratio of the volume after 30 minutes settling to the actual weight of sludge in the effluent. Since the character of the sludge did not change appreciably in the short period spent at each plant, it seems logical to conclude that the volume occupied by the sludge does bear a rather definite relation to the actual weight of sludge present as long as the character of the sludge remains the same. This relation is, however, affected to a surprising extent by any change in the character of the sludge.

At the Houston south side plant, where the highest ratio, 42, was obtained, the sludge was characterized as "very good sludge" and the plant was in very good working order. At the Houston north side plant where the average ratio was 23, some difficulty had been experienced with the sludge just previous to the survey. The sewage treated at this plant is not much stronger than at the south side plant, and the final effluent, although very highly purified, was not quite as good as that from the South Side plant. At San Marcos, where the ratio is about 8, the sewage receives some preliminary treatment before reaching the activated-sludge plant, by which a good part of the suspended matter is removed. The 5-day oxygen demand of the effluent from this plant is about twice as great as that of the Houston plants, and the 5-day oxygen demand of the plant influent is only about one-half as great. This plant could not be said to be working as efficiently as the larger Houston plants. The Sherman plant was admittedly out of order, and the sludge could very well be characterized as "bad" sludge. The ratio derived is about 5.

From the above discussion it would appear that, for an accurate estimate of the quality of activated sludge, the volume occupied by the settled sludge as well as its suspended matter content must be determined. It also appears, from the comparison of the ratios of the suspended matter to the volume, that the volumes obtained after 15 minutes of settling will give information of about the same degree of reliability as if the longer period of 30 minutes had been used.

6. SUSPENDED MATTER.

This test is of fundamental importance in sewage analysis both as a guide in the design of a plant and as an aid to its proper operation. Using the Gooch crucible method, the determination can be made with a relatively high degree of accuracy, the probable error varying with the character of the suspended matter. The main source of error is due to the difficulty of securing a representative sample since, without a disproportionate expenditure of time, it is seldom possible to filter more than 50 to 100 c. c. of sewage. With a raw sewage the tendency is for the results to be too low, due to the necessary exclusion of the larger particles such as fruit skins, and other substances of similar nature which are best described as settleable solids. If these coarser particles are first removed and the balance of the sewage is well disintegrated, as by vigorous shaking, the accuracy of the test is considerably increased. This is well illustrated by the following results obtained at Rochester in a study of Riensch-Wurl screens.

TABLE No. 13.—*Variations in suspended matter determinations.*

[Results in parts per million.]

Date.	Raw sewage.				Riensch-Wurl screen effluent.			
	Duplicates.		Average.	Per cent deviation.	Duplicates.		Average.	Per cent deviation.
	A.	B.			C.	D.		
1920.								
July 24	460	296	378	21.8	312	308	310	0.6
26	250	264	257	2.7	286	280	283	1.1
27	204	190	197	3.5	202	206	204	1.0
28	138	128	133	3.8	132	136	134	1.5
29	164	122	143	14.7	144	148	146	1.4
Averages	243	200	222	±9.3	215	216	215	±1.1

All tests recorded in the above table were made on samples composited over 24-hour periods. Before removing a portion for the test, the bottles were shaken vigorously and every precaution was taken to make the analyses comparable in every way. The results tabulated under columns A and B are duplicate determinations made on the raw sewage, and the results under columns C and D are duplicate determinations made on the Riensch-Wurl screen effluent. This effluent was in every way comparable with the raw sewage excepting that the coarser particles had been removed and the rest of the suspended matter had been well disintegrated by the action of the brushes. The result was a sample with a very homogeneous suspended matter content. This is indicated by the excellent agreement between the duplicate determinations and the low average deviation, 1.1 per cent, which in this case is a measure of the probable error involved. The corresponding raw sewage samples collected and tested under exactly the same conditions show an average deviation of 9.3 per cent from the average value obtained when duplicate tests are made.

The series of tests presented is not sufficiently extensive to be made the basis of very definite conclusions. It nevertheless confirms a general opinion and shows an unmistakable tendency. A more extensive series of tests presented in Table No. 41 indicates that the suspended matter content increased by about 5 per cent on passing through the Riensch-Wurl screen. This obviously questionable result is readily explained if it is considered that the results for the suspended matter content of the raw sewage may be in error by over 9 per cent and that the tendency is for the raw sewage results to be too low. The amount of suspended matter removed by the Riensch-Wurl screen would have to be in the neighborhood of 10 or 15 per cent before any removal could be indicated with certainty by suspended matter determinations. A direct weighing of the screenings removed is, of course, the indicated method of procedure. The limitations of the suspended matter determination do not lead to serious errors of interpretation, however, when the test is applied to the effluents of the ordinary devices. Since in any complete system of sewage treatment the removal of the bulk of the suspended matter in the form of sludge is one of the main objectives, this determination is of great value and in most cases an error of 10 per cent, or even more, does not affect the validity of the conclusions drawn. The test is especially useful for the estimation of the per cent removal effected by the various types of tanks and is the best index available for judging the efficiency of tank treatment.

The suspended matter determination is also of great importance in estimating the fitness of effluents from oxidizing devices for discharge into streams, since an imperfect removal of suspended matter is probably a more frequent cause of gross nuisance than an insufficient stabilization of the soluble impurities in the sewage. For this reason the suspended matter content of the final effluent is a test which can not very well be omitted in an analysis of sewage.

7. AMMONIA NITROGEN.

This test was made only at the four activated sludge plants visited during the survey. In the following table the values obtained are compared with the results of two other determinations.

TABLE No. 14.—*Comparison of the ammonia nitrogen content of sewage at different stages of purification with the results of other determinations.*

Plant.	Raw sewage.		Septic tank effluent.		Final effluent.		
	Ammonia nitrogen.	5-day oxygen demand.	Ammonia nitrogen.	5-day oxygen demand.	Ammonia nitrogen.	5-day oxygen demand.	Nitrogen as nitrates.
San Marcos	15	67	17	57	2.8	16	5.8
Houston (south side)	18	112			1.7	7.4	6.0
Houston (north side)	17	115			4.3	11	4.6
Sherman	25	202			23	40	1.2

While no definite conclusions can be derived from such a small number of observations, the indications are that the ammonia nitrogen content, in general, varies directly with the oxygen demand and inversely with the nitrate content, i. e., a low nitrogen content is correlated with a low oxygen demand and high nitrates. On the whole the determination appears to be of value at activated sludge plants. The test can very readily be performed if the direct nesslerization method is used. The information furnished by the test is of corroboratory nature and its usefulness is limited to that extent.

Considering the results presented in Table No. 14, it is evident that if the ammonia nitrogen had been completely converted into nitrates, the nitrate content of the final effluents from the Houston plants would have been 7.7 at the south side plant and 8.9 at the north side plant. Even if an allowance is made for the presence of forms of nitrogen other than ammonia nitrogen, the total potential nitrates at these activated sludge plants would hardly exceed 10 or 12 parts per million. In this connection it is to be noted that a considerable portion of the total nitrogen disappears during the aeration process, presumably as free nitrogen. If no nitrogen was lost, the potential nitrification might reach 30 or 40 parts per million.

8. ETHER-SOLUBLE MATTER (FATS).

The ether-soluble matter of the raw sewage was determined at all plants visited. The results, summarized in Table No. 15, indicate that the quantity of this constituent is subject to considerable variation.

TABLE NO. 15.—*Comparison of the ether-soluble matter (fat) content of raw sewage with its 5-day oxygen demand.*

[Results in parts per million.]

Determination.	Rochester (Brighton).	San Marcos.	Rochester (Irondequoit).	Houston (south side).	Alliance.	Houston (north side).	Baltimore.	Lexington.	Canton.	Fitchburg.	Sherman.	Columbus.	Atlanta (Peachtree).	Atlanta (Intrench.).
Ether-soluble matter	16	18	34	36	37	39	40	58	62	63	69	100	83	104
5-day oxygen demand	67	67	104	112	92	115	120	144	213	154	202	190	52	62
Ratio	4.2	3.7	3.1	3.1	2.5	2.9	3.0	2.5	3.4	2.4	2.9	1.9	.....	.....

In the above table the plants are arranged in the ascending order of magnitude of the ether-soluble matter content of the respective sewages excepting the Atlanta Peachtree plant. At both the Atlanta plants the ether-soluble matter content appears to be disproportionately high. Assuming the ether-soluble matter content of the average sewage to be about 40 parts per million, the total fat content of sewage is about 330 pounds per million gallons or one-half ounce per capita per day.

The ether-soluble matter appears to vary somewhat directly with the 5-day oxygen demand. Except at the Atlanta plants, the oxygen demand is about three times as great as the ether-soluble matter content.

This determination was also made on sewage sludges. The results are presented in Table No. 62.

9. Oxygen Consumed.

While this test has lost a great deal of its former importance due to the introduction of biochemical oxygen demand methods, it is, nevertheless, so generally in use that it was thought advisable to include it in the tests made during the survey. The significance of the test is best shown by a comparison with the corresponding oxygen demand values.

Table No. 16.—*Comparison of permanganate oxygen consumed with 5 day biochemical oxygen demand results.*

[Results in parts per million.]

Plant.	Analyses at various stages of operation.									Percentage purification effected as judged by—	
	Raw sewage.			Tank effluents.			Filter or final effluents.				
	Oxygen consumed.	5-day oxygen demand.	Ratio.	Oxygen consumed.	5-day oxygen demand.	Ratio.	Oxygen consumed.	5-day oxygen demand.	Ratio.	Oxygen consumed.	5-day oxygen demand.
Rochester (Brighton)	24	67	2.8	15	36	2.4	5.9	5.2	0.9	75	92
San Marcos	29	67	2.3	18	57	3.2	8.5	16.0	1.9	71	76
Lexington	32	144	4.5	22	87	4.0	9.5	15.0	1.6	69	89
Atlanta (Intrench.)	35	62	1.8	21	23	1.1	10.0	4.2	.4	71	93
Atlanta (Peachtree)	35	52	1.5	18	20	1.1	7.0	2.9	.6	80	92
Alliance	38	92	2.4	26	68	2.6	11.0	20.0	1.8	71	78
Houston (south side)	38	112	3.0	......	......	......	6.4	7.4	1.2	83	93
Rochester (Irondequoit)	39	104	2.7	35	74	2.1	......	......	......	......	......
Baltimore	43	120	2.8	36	125	3.5	8.2	12.0	1.4	81	90
Houston (north side)	45	115	2.6	......	......	......	10.0	11.0	1.1	78	90
Reading	45	118	2.6	31	96	2.1	14.0	15.0	1.1	69	87
Canton	61	213	3.5	35	120	3.4	18.0	37.0	2.0	70	83
Columbus	63	190	3.0	46	134	2.9	28.0	49.0	1.8	56	74
Sherman	64	202	3.2	......	......	......	37.0	40.0	1.2	50	80
Fitchburg	65	154	2.4	37	95	2.6	16.0	21.0	1.3	75	86
Average	......	......	2.7	......	......	2.7	......	......	1.3	71	86

The average ratio derived for raw sewages and tank effluents is 2.7, while for relatively highly purified effluents it is only 1.3. As the raw sewage becomes more and more purified the two values, apparently, tend to approach each other. This dependence of the value of the oxygen consumed on the state of oxidation, constitutes a strong objection to the method and invalidates the use of a universal factor for the conversion of this quantity into terms of oxygen-demand units. The explanation is apparent if it is remembered that the oxygen-consumed test measures, roughly, only the carbonaceous portion of the polluting material, whereas, the oxygen-demand test includes both carbonaceous and nitrogenous impurities. It is not to be expected that the ratio of the values obtained by the two methods will be constant unless the proportion of nitrogenous to carbonaceous matter is likewise constant. This condition is approximately fulfilled in the case of raw sewage. If the relative proportion of carbonaceous matter is disturbed, as by an oxidation device, the conversion factor will be altered correspondingly.

A practical deduction is that the efficiency of a plant will appear to be lower when the reduction in the amount of polluting material is measured in terms of the reduction in the oxygen consumed than when it is measured in terms of the reduction in the biochemical oxygen demand. At Rochester, Brighton, for example, the degree of purification accomplished is 75 per cent if measured by the reduction in the oxygen consumed and 92 per cent if measured by the reduction in the oxygen demand. From another point of view, the amount of polluting material which left the plant unpurified was 25 per cent in one case and 8 per cent in the other. The higher value of 92 per cent reduction is undoubtedly more nearly correct than the low value of 75 per cent.

It is hardly necessary to state that the values given can not be used for a direct comparison of the plants visited without many qualifying remarks as to the degree of purification sought, the methods of treatment, the load on the plant, rainfall, presence of secondary sedimentation tanks, etc. The general average derived, however, is probably a good index of the condition of the plants as a whole. Judged by the oxygen-consumed results, the average degree of purification effected is only 71 per cent; the oxygen-demand data, however, indicate an average purification of 86 per cent. It is believed that the value of 86 per cent derived from the oxygen-demand results more nearly represents the average performance of the plants visited than the low value of 71 per cent.

In this connection it is to be noted that the oxygen-demand and oxygen-consumed values presented in Table No. 16 are uncorrected for the presence of nitrites. Even if such a correction were to be applied, however, the general conclusions would hardly be affected. It is debatable, in any event, whether the nitrites are a debit or a credit to a sewage effluent. If the effluent is very highly purified they are certainly to be debited since oxygen will be abstracted from the receiving body of water before they are converted into nitrates. If the effluent is of poor quality, the nitrites may be a negligible asset, since a nuisance condition may be created before nitrite oxygen is drawn upon. Furthermore, a similar correction would have to be applied to the oxygen demand results.

10. DISSOLVED OXYGEN.

This test was made at all plants on 24-hour composites of the raw sewage and the final effluents. The dissolved oxygen was also determined in the Imhoff tank effluent at Rochester, Brighton, and in the septic-tank effluent at San Marcos.

The dissolved oxygen content of raw sewages and final effluents as determined during the survey is possibly not a fair index of its actual value, since of necessity the tests were made on samples iced over a 24-hour period. It can not be stated with certainty that the oxygen content of a sample is unaffected under these conditions.

The dissolved oxygen content of raw sewage is subject to great diurnal and seasonal variations and is also affected by factors such as storm flows, the presence of industrial wastes, such as ferrous salts, the distance traveled before reaching the plant, etc. In general, the determination does not furnish information of great value when applied to raw sewage.

The presence of dissolved oxygen in the tank effluents at Rochester, Brighton, and at San Marcos is an unusual condition. The sewage at both of these plants is very weak and travels only a very short distance before reaching the plants.

In the final effluents the determination of dissolved oxygen is of more importance, although it is greatly affected by temperature and other factors, such as the presence of oxygen-forming algae. The average values obtained are presented in Table No. 17.

TABLE NO. 17.—*Comparison of the dissolved oxygen content and the 5-day oxygen demand of effluents from various oxidizing devices.*

Determination.	Trickling filters.								Activated sludge.			
	Reading.	Columbus.	Lexington.	Baltimore.	Atlanta (Intrench.).	Atlanta (Peachtree).	Fitchburg.	Rochester (Brighton).	Houston (north side).	Sherman.	Houston (south side).	San Marcos.
5-day oxygen demand......	15	40	16	8.3	4.2	3.9	21	5.2	11	40	7.4	16
Dissolved oxygen...........	3.7	4.8	5.2	5.2	5.4	5.7	7.9	8.0	5.2	6.2	7.4	7.6

In the above table the dissolved oxygen results have been arranged in the ascending order of their magnitude for various oxidizing devices, and the corresponding oxygen demand results have been included for comparison. In general, the dissolved-oxygen content is not correlated with the oxygen demand of the sample. If temperature effects, however, are eliminated by comparing plants in the same city, e. g., the Atlanta plants or the Houston plants, the dissolved oxygen content appears to vary inversely with the oxygen demand, as would be expected. For the proper interpretation of dissolved oxygen results a knowledge of the temperature conditions is essential. On the whole it appears that the determination of the dissolved oxygen content of an effluent possesses its greatest value when used as an adjunct of the biochemical oxygen demand test.

11. BIOCHEMICAL OXYGEN DEMAND.

This test was made on the raw sewages and the various effluents at all plants visited. Throughout the preceding discussion the other tests used in sewage analysis have been compared with the corresponding oxygen demand value. The test appears to furnish by far the most valuable information as to the behavior of the plants and the efficiency of the various devices used in sewage purification. With suitable precautions, a high degree of accuracy is attainable, and once a routine has been established the time and labor involved is no greater than is required for a nitrate determination or an oxygen-consumed test. The oxygen demand determination has the decided advantage that it is applicable to sewage in all stages of purification, and the information that it furnishes can be used independently of the results of other determinations.

When dilutions are made with raw sewage, the degree of dilution can be used in estimating its effect on a receiving body of water. In the absence of bacteriological data the determination of the oxygen demand of a stream above and below the point where an effluent is discharged is probably the best index of the effect of the sewage on the stream.

12. SLUDGE ANALYSES.

Samples of sludge were taken at most of the plants visited, and complete analyses are presented in Table No. 62.

For routine work determinations of moisture content and specific gravity are of importance. Where the sludge is being advocated for use as a fertilizer, total nitrogen determinations are of course essential.

In the interpretation of data on the specific gravity of sludge it is to be remembered that the specific gravity as determined analytically does not represent the specific gravity of the sludge when it is in the bottom of a tank under a head of 20 to 30 feet of water. On being brought to atmospheric pressure a good portion of the dissolved gases may be liberated, and this may affect the specific gravity to a considerable degree.

CONCLUSIONS BASED ON LABORATORY STUDIES.

Sewage, analytically considered, may be conveniently resolved into its soluble or colloidal and its suspended or readily settleable constituents. Practically the aim of all methods of sewage treatment is the oxidation of the soluble or colloidal portion and the removal of the suspended or readily settleable portion as an inoffensive or even a marketable sludge. The aim of sewage analysis, therefore, should be to determine both the degree to which the removal of suspended matter has been effected and the state of oxidation of the soluble portion which is to be discharged into a stream. The suspended matter determination by the Gooch crucible method is very generally accepted as a satisfactory method for estimating the removal of the suspended matter. Opinions differ widely, however, in the choice of suitable methods for the estimation of the degree of oxidation effected, and it is believed that progress in sewage treatment is being greatly retarded by this lack of agreement.

Based on the results obtained during the survey and the results of extensive tests on industrial wastes and several river waters, it appears that the 5-day biochemical oxygen demand as determined by the excess-oxygen method is the best method available for estimating the strength of a raw sewage, the efficiency of the various devices used in sewage purification, and the quality of the effluents produced.

These two tests, the oxygen demand and the suspended matter, seem to be capable of furnishing about all the analytical data that is required for the proper operation of the ordinary sewage treatment plant, and are suggested as an irreducible minimum of laboratory work. At activated sludge plants the settleable solids and the ammonia nitrogen should be determined in addition. Other tests are of value as additional circumstantial evidence but should not be added to a routine schedule unless for research purposes or where special conditions make it necessary to do so.

In this connection it must be remembered that the analytical work during this survey was restricted to chemical studies. No mention is, therefore, made of the bacteriological tests, though it is appreciated that they are valuable and essential at some plants. Moreover, tests designed to furnish information as to the fitness of sludge for withdrawal do not seem to be developed sufficiently to warrant any definite recommendation.

Determinations of nitrogen in its various forms are time-honored procedures which furnish more or less useful indirect information but do not appear to be essential for efficient plant operation. These tests are generally time consuming and, at best, furnish information on only half the polluting material present, the nitrogenous.

Nitrate determinations may be useful in estimating the quality of an effluent but of course can not be used for estimating the strength of a raw sewage. Ammonia nitrogen determinations are very readily made, using the direct method, but do not furnish very reliable information in most cases. Albuminoid ammonia and total nitrogen determinations, requiring considerable apparatus and time, can hardly be used to estimate the percentage purification effected by a plant. Their use for this purpose dates back to a time when no better methods were available.

The oxygen-consumed test furnishes information as to the amount of carbonaceous material present but does not include a considerable portion of the nitrogenous impurity, the ammonia nitrogen. If worked together, the various nitrogen determinations and the oxygen-consumed test can be made to give a fair idea of the degree of purification effected, but only with a considerable expenditure of time and effort which does not seem justified in view of the sometimes misleading results obtained.

The above discussion applies without much qualification to plants where chemists are employed. At some plants where chemists can not be employed the readily performed relative stability and settleable solids determinations are the safest and best fitted for the purpose of supplying the plant foreman with some information as to the strength of a raw sewage and the quality of an effluent.

CHAPTER IV.

SUMMARY OF ENGINEERING DATA AND CHEMICAL ANALYSES OBTAINED AT THE PLANTS SURVEYED.

I. ALLIANCE, OHIO.

The engineering survey of the sewage treatment plant at Alliance, Ohio, covered the period May 26 to June 6, inclusive. The laboratory work was started with the sample of June 1st, and continued through the sample of the 14th.

Alliance is a thriving industrial city located in the northeastern part of Ohio on the main line of the Pennsylvania Railroad, and in 1920 had a population of 21,603. The industries are largely those devoted to the manufacture of machinery and heavy iron goods.

The sewerage system is built on the separate plan, but it is admitted that some down spouts are connected. The total contributing population is estimated at 20,000. The system as a whole is divided into two parts, the high-level system, serving about 95 per cent of the contributing population and feeding to the treatment plant by gravity, and the low-level system, serving the remaining 5 per cent of the population and feeding to the site of an old sewage treatment plant where the sewage, after passing through septic tanks flows to pumps at the main treatment plant, which lift it to the influent channel receiving the sewage from the high-level system.

The septic tanks at the old treatment plant probably affect the operation of the main plant little if any. They are not considered, therefore, as part of the treatment, but as part of the sewerage system, serving as a protection to the pumps. There are three tanks each 80 by 40 by 6 feet deep, connected in series. The inlets and outlets are all on the same end, and, as there are no baffles, the sewage probably does not travel more than 15 to 20 feet of the 80-foot length. The tanks were last cleaned about five years ago. The effluent varies greatly, being at times very good and at other times black and highly septic.

Infiltration and leakage is claimed by local officials to be very high. Reference was made to a figure of 185,000 gallons per mile per day given by Metcalf and Eddy.[1] An investigation by the Ohio State Board of Health [2] brought out the fact that the sewage flow was at a rate of 246 gallons per capita per day. The excess above normal was attributed to leakage and excessive use of water in flush tanks.

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[1] American Sewerage Practice, vol. 1, p. 186, table 56.

[2] Report on an Investigation of Water and Sewage Purification Plants in Ohio. Ohio State Board of Health, 1908.

It is probable, however, that both of these figures quoted apply to the low-level sewers. Here there is evidence of excessive infiltration. As already stated, this system is estimated to serve only 5 per cent of the total contributing population, or 1,000 to 1,200 people, and yet about 25 per cent of the total sewage flow is received from it. While both the population and flow factors are estimates, they are probably accurate enough, within normal errors of estimation, to indicate that leakage on this system is very high.

Other data obtained during this survey would indicate that these conditions do not apply to the entire sewerage system, including the high-level sewers. The average flow for the year, May, 1919, to April, 1920, was at a rate of 124 gallons per capita per day, and the maximum for any day during that period was 214 gallons. If the entire excess of this last figure over a conservative estimate of 100 gallons per capita per day be considered leakage, without making any allowances for down spouts the average leakage for the entire system would be 48,000 gallons per mile per day.

Grades for sewers throughout the city are good. On the high-level system the average grade is 1 per cent with variations from 0.5 to 2 per cent, except that the main outfall sewer has a grade of 0.3 per cent. The average for the low-level system is 0.3 per cent.

Sewer cleaning is done almost entirely with fire hose. There are some flush tanks on dead ends, but most of these are idle.

The total mileage of all sewers in both the high and low level systems is 51.7. This is divided among the various sizes of pipe as given below.

	Lin. ft.		Lin. ft.
4-inch vit	430	15-inch vit	10,660
6-inch vit	52,771	18-inch vit	4,021
8-inch vit	131,424	20-inch vit	3,226
10-inch vit	31,518	24-inch vit	5,796
12-inch vit	28,490	30-inch concrete	4,525

There are only 1,574 recorded connections to the sanitary sewers, but this is because records have been kept for only recent years. The city engineer, Mr. Homer Anderson, and the plumbing inspector estimate that there are in all from 4,800 to 5,000 active connections. This estimate is well checked by the water department which stated that there were about 5,200 active water connections, of which approximately 98 per cent served toilet facilities.

The sewage received at the treatment plant is typically domestic. That from the high-level system, constituting about 75 per cent of the total, is fresh, while that from the low-level system is, at times, very septic. When combined, however, the dilution of the septic sewage is great enough to give the mixture the characteristics of a fresh sewage. It has a whitish gray color and contains the usual floating and suspended solids consisting of paper, matches, fecal matter, fruit and vegetable skins, etc. There are no indications of any industrial wastes confirming the claim that no waste producing industries other than laundries contribute more than sanitary sewage.

The average flow for the year preceding this survey was 2.62 m. g. d., and the monthly averages vary little from this figure. The maximum 24-hour flow for this period was 4.5 m. g. For short periods during a day rates run as low as 1.5 and as high as 7.0 m. g. d.

The following table contains the flow data for the year May, 1919, to April, 1920:

TABLE NO. 18.—*Volume of sewage treated at Alliance, Ohio, for period indicated.*

[Figures in million gallons per day.]

1919	Average.	Maximum.	Minimum.	1919–20	Average.	Maximum.	Minimum.
May	2.98	3.86	1.95	November	2.83	3.41	2.54
June	2.61	3.09	1.60	December	2.90	4.50	1.68
July	2.47	3.00	1.98	January	2.32	2.76	1.73
August	2.50	3.43	1.98	February	2.40	2.80	1.55
September	2.47	3.17	2.14	March	2.59	3.42	1.97
October	2.85	3.87	1.98	April	2.58	3.65	1.97

Sewage treatment was first started in 1893 with a chemical precipitation plant and sludge presses. This plant was abandoned, except for the septic tanks which have already been described in the discussion of the low-level sewerage system, and was superseded in 1913 by a plant, designed by Messrs. Bradbury and Shute, consisting of grit chambers, bar screens, sedimentation tanks, contact beds, intermittent filters, and sludge beds. This plant is still operating, though modified, and, in some respects, enlarged in accordance with plans prepared by Mr. R. W. Pratt in 1915.

As it now stands the original grit chambers act merely as influent channels, one chamber for the high-level sewage and another for the low-level, which latter is pumped by a small automatic pumping station located on the grounds of the treatment plant. The two sewages are combined at the outlet of the old grit chambers and flow over a measuring weir to the bar screen. This screen is hand raked during the day as needed and left clean when the laborers leave at night. There is no night operator. The screenings are removed in a wheelbarrow to a dump on the plant grounds. About 4 to 6 cubic feet of screenings per day or roughly 2 cubic feet per million gallons are retained by the bar screen.

The screened sewage is distributed to one or both of two plain sedimentation tanks and to two Imhoff tanks, each of the latter having four flow chambers. The plain sedimentation tanks are run on a nine-day schedule. A tank is put into operation on Monday morning and run till a week from the following Wednesday when it is shut down, drained, and cleaned. In this way the two tanks are alternated, but on Mondays and Tuesdays of each week they are both operated. When a tank is taken out of service, the supernatant sewage is drained to a fine grain cinder filter reserved for this purpose and the sludge is then pumped by an ejector to the sludge chamber of an Imhoff tank for digestion. The total flow of sewage is divided roughly half-and-half between the plain sedimentation tanks and the Imhoff tanks.

The two Imhoff tanks are operated continuously. These tanks were constructed within an old sedimentation tank identical in design and construction with the two already mentioned. The bottom was taken out, hoppers built, and the Imhoff baffles placed, the longitudinal axis of the sedimentation tank being made the transverse axis of the Imhoff tank. The length of the sedimentation tank provided sufficient width for eight Imhoff flow channels, but as the digestion space is divided into only two sections, the tanks have been considered as two tanks with four flow channels each. The inlet and outlet channels are arranged to permit reversing the direction of flow.

In the operation of the Imhoff tanks, considerable difficulty has been experienced with the formation of scum in the flow channels. This appeared from the inspection to be due to one of or a combination of three causes: First, insufficient or too infrequent squeegeeing of the sloping bottoms of the flow channel; second, inadequate removal of sludge, which resulted in the sludge level rising above the bottom slot of the flow channel; and third, agitation and pressure production in the digestion chamber by pumping sludge from the sedimentation tanks to the Imhoff tanks. The discharge line from the ejector serving the sedimentation tanks enters the Imhoff tanks from the top through the gas vents, but extends down into the tank about six feet. The entering sludge is, therefore, pumped into the Imhoff tanks with considerable downward velocity toward the sludge already in the digestion chamber. This stirs up the sludge and forces it back through the slots into the flow channel.

The sludge from the Imhoff tanks is run to an ejector which pumps it to glass-covered beds. There is available also some uncovered drying area but this is used very little. The operators appeared well satisfied with the glass-covered beds, stating that they were more independent of weather conditions than the open beds. However, the drying period was admittedly affected to some extent by seasons and weather. It averages from 8 to 14 days. Sludge is not measured in the tank or when run on the bed, but only when removed from the beds. As no determination is made of the moisture content, only a rough estimate of sludge production is possible.

The effluents from both the sedimentation tanks and the Imhoff tanks are combined and applied to 12 contact beds of ¼ acre each.

38a

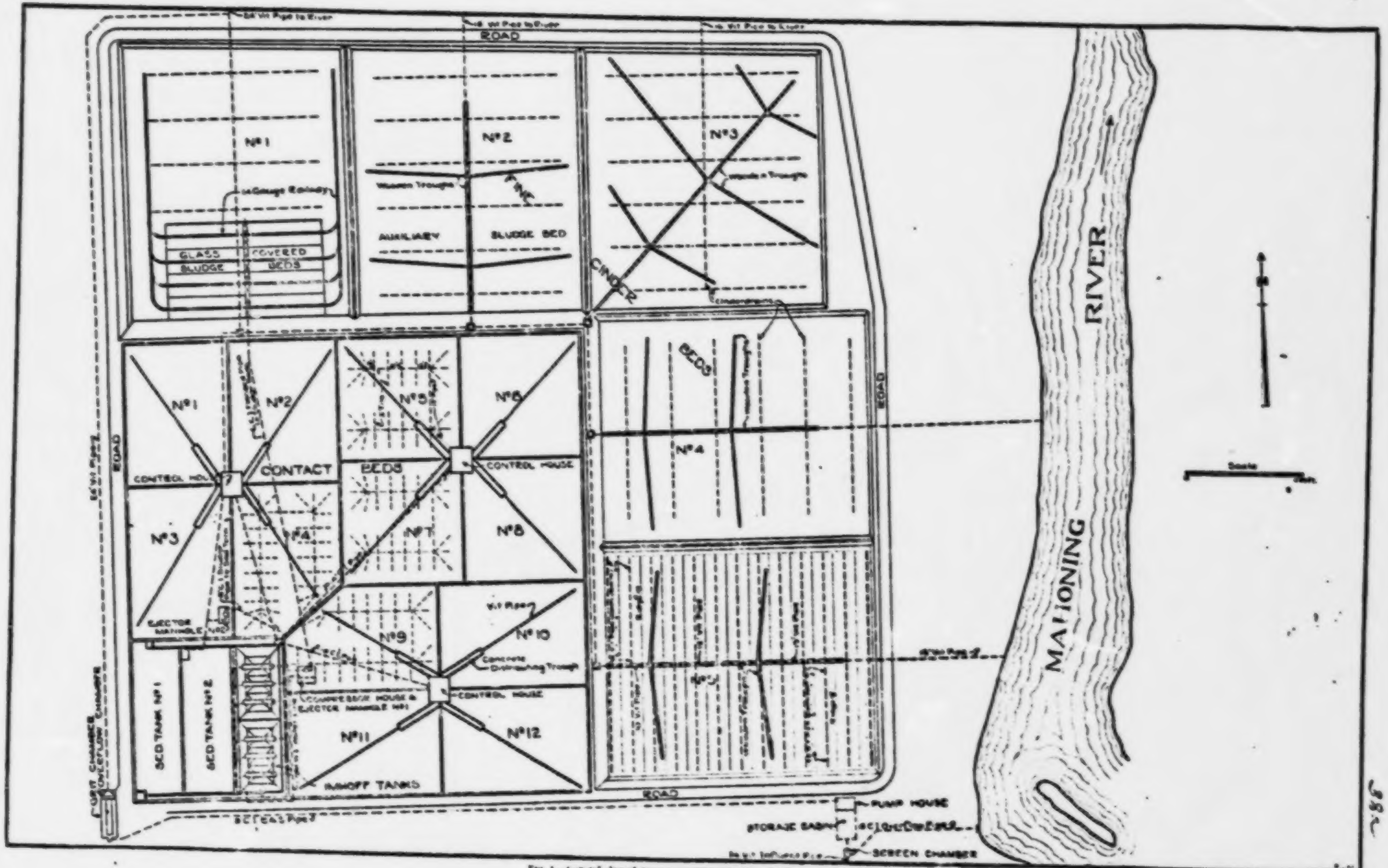
ROAD
Nº1
GLASS COVERED
SLUDGE BEDS
Nº2
Wooden Troughs
AUXILIARY SLUDGE BED
Nº3
CINDER
BEDS
Nº4
Nº1
Nº2
CONTACT
BEDS
CONTROL HOUSE
Nº3
Nº4
Nº5
Nº6
Nº7
Nº8
CONTROL HOUSE
EJECTOR MANHOLE
Nº9
Nº10
Concrete Distributing Trough
COMPRESSOR HOUSE & EJECTOR MANHOLE Nº1
CONTROL HOUSE
Nº11
Nº12
IMHOFF TANKS
SED TANK Nº1
SED TANK Nº2
GRIT CHAMBER
OVERFLOW CHAMBER
ROAD
PUMP HOUSE
STORAGE BASIN
SCREEN CHAMBER
MAHONING
RIVER
Scale

Fig. 1.—General plan of the sewage-treatment plant at Alliance, Ohio.

3612—B. (Face p. 26)

38b

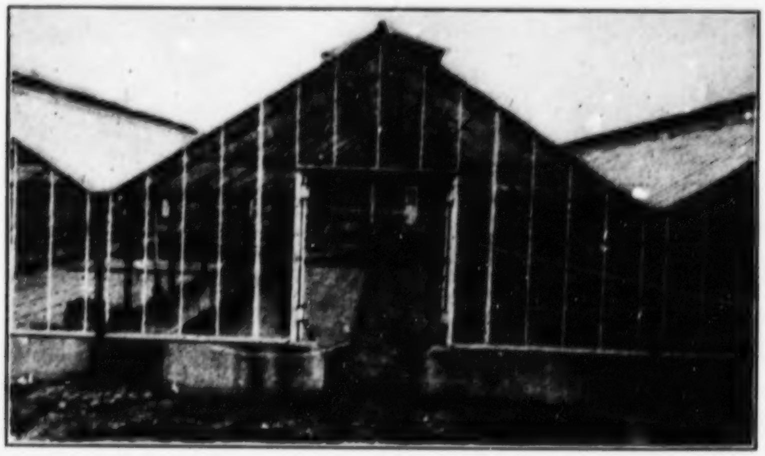

FIG. 2.—GLASS COVERED SLUDGE BEDS AT ALLIANCE, OHIO.

These beds are arranged in three units of four each and dosed by automatic air controlled siphons, which rotate the doses on the four beds of each unit. The effluent from these beds during the late fall, winter, and early spring is discharged directly into the Mahoning River. During the warm months, however, it is again treated on three intermittent filters of one acre each.

Overflows and bypasses are available at various points to protect against flooding of the plant grounds or to cut out entirely the whole plant or any single device.

Rather inadequate laboratory facilities are provided in the laboratory of the water-filtration plant, about a half mile from the sewage plant. The room used for this purpose is small, making it very difficult to carry on the work of two departments by two different men. This condition has now (1921) been improved by placing the water-filtration and sewage-treatment plants under one chemist.

The personnel consists of the chemist, dividing his time between the water and sewage plants, and a superintendent with one assistant. For special work, such as weeding filter beds, cutting grass, etc., additional labor is provided. With the labor available, very little time can be devoted to the upkeep of the grounds.

The results of the chemical analyses made at this plant are contained in the following table:

Table No. 19.—*Results of chemical analyses at the Alliance, Ohio, sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample, ending 8 a. m.—	Suspended matter.					Settleable solids, 2 hours c. c. per liter.[1]				Oxygen consumed 30′ in boiling water.				Alkalinity as $CaCO_3$ by M. O.				Ether soluble matter 24-hour comp. raw.	Chlorine as chlorides.			
	Raw.	Effluent of tanks.	Effluent primary contact beds.	Effluent secondary fine cinder filters.	Raw supernatant.	Raw.	Effluent of tanks.	Effluent primary contact beds.	Effluent secondary fine cinder filters.	Raw.	Effluent of tanks.	Effluent primary contact beds.	Effluent secondary fine cinder filters.	Raw.	Effluent of tanks.	Effluent primary contact beds.	Effluent secondary fine cinder filters.		Raw.	Effluent of tanks.	Effluent primary contact beds.	Effluent secondary fine cinder filters.
June 2	130	74	18	....	26	4.0	0.1	Tr.	....	40	29	13.0	....	206	206	162	....	60	41	44	46	....
3	474	11	25	....	72	5.0	.6	Tr.	....	52	24	6.4	....	136	178	154	....	46	44	44	44	....
4	104	66	18	....	24	1.0	Tr.	Tr.	....	29	35	10.0	....	152	162	156	....	32	53	43	41	....
5	98	56	18	....	32	.8	Tr.	Tr.	....	30	22	19.0	....	158	178	150	....	37	42	42	40	....
6	104	55	21	....	35	1.6	Tr.	Tr.	....	34	26	9.6	....	172	188	136	....	28	47	50	48	....
8	150	70	22	....	50	2.0	Tr.	Tr.	....	52	20	15.0	....	176	200	178	....	42	44	46	46	....
9	160	71	....	....	32	1.8	Tr.	....	....	78	19	....	....	164	192	....	....	25	40	41	....	....
10	114	....	....	....	30	1.4	....	....	....	36	....	....	....	188	....	....	....	22	44	....	....	....
11	100	72	16	....	34	1.0	Tr.	Tr.	....	40	30	9.2	....	196	198	176	....	31	45	48	46	....
12	116	58	14	....	32	1.0	Tr.	Tr.	....	30	29	12.0	....	212	210	176	....	35	60	58	55	....
14	128	54	4	0	28	2.0	Tr.	Tr.	Tr.	34	18	6.3	5.4	198	200	174	162	45	54	53	51	52
15	....	67	14	0	40	2.0	Tr.	Tr.	Tr.	33	26	10.0	5.2	226	224	184	170	41	48	55	52	50
Average	152	60	17	0	37	2.0	Tr.	Tr.	Tr.	38	26	11.0	5.3	184	194	167	166	37	47	47	48	51

[1] Tr. means less than 0.1 c. c.

TABLE No. 19.—*Results of chemical analyses at the Alliance, Ohio, sewage-treatment plant*—Continued.

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.								Dissolved oxygen.			Hours to reduce M. B. at 20° ± C.						Nitrogen as nitrates.	
	Raw.		Effluent of tanks.		Effluent primary contact beds.		Effluent secondary fine cinder filters.		Raw.	Effluent primary contact beds.	Effluent secondary fine cinder filters.	Raw.		Effluent of tanks.		Effluent primary contact beds.		Effluent primary contact beds.	Effluent secondary fine cinder filters.
												Per cent concentration.							
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.				10	20	10	20	5	100		
June 2	44	80	36	60	2.0	9.0	.....	.....	.....	3.2	.....	.....	.....	.....	.....	.....	.....	2.4	.....
3	36	120	24	56	0.9	11.0	.....	.....	0.0	2.0	.....	.....	.....	.....	.....	.....	.....	2.8	.....
4	20	74	20	84	8.0	22.0	.....	.....	3.4	6.0	.....	[1]264+	.....	[1]264+	.....	264+	.....	3.2	.....
5	22	74	16	56	6.0	19.0	.....	.....	2.5	4.6	.....	[1]72	72	.....	192	.....	168	3.0	.....
6	60	104	52	76	14.0	40.0	.....	.....	3.5	7.4	.....	.....	40	.....	48	.....	216+	3.2	.....
8	56	124	40	92	16.0	34.0	.....	.....	4.2	5.8	.....	.....	.....	.....	.....	.....	.....	2.2	.....
9	20	80	16	44	.....	.....	.....	.....	4.3	.....	.....	.....	44	.....	60	.....	.....	.....	.....
10	24	60	.....	.....	.....	.....	.....	.....	4.2	.....	.....	72	48	.....	.....	.....	.....	.....	.....
11	36	74	28	76	5.0	15.0	.....	.....	5.4	8.5	.....	144+	24	144+	24	.....	144+	2.2	.....
12	36	80	28	84	5.0	17.0	.....	.....	2.9	6.6	.....	72+	24	72+	48	.....	120+	2.0	.....
14	34	78	14	34	0.5	6.5	1.4	4.6	1.6	7.4	9.1	72	48	.....	.....	.....	.....	4.5	5.0
15	44	144	40	88	6.0	15.0	.....	6.1	1.4	7.0	8.6	.....	48	.....	48	.....	.....	1.6	3.0
Average	36	92	28	68	6.0	20.0	1.4	5.3	3.0	5.7	8.8	.....	.....	.....	.....	.....	.....	2.8	4.0

[1] 5 per cent.

The efficiency of the various treatment devices is made a separate section of this report, as is also a detailed discussion of the interpretation and value of different determinations. Only a few general remarks, based on the analyses in the above table, will, therefore, be made at this point.

The presence of dissolved oxygen in the raw sewage on all days except one confirms a statement previously made that the sewage is received at the plant in a fresh condition. This is further evidenced by the extent to which the settleable solids are removed in the tank, indicating that there is very little breaking up of these solids in the travel in the sewers to the plant. Besides being fresh, the sewage is rather weaker than the average. This is best shown by the 5-day oxygen demand results, which average only 92 parts per million with a maximum of 144.

The final intermittent filters were operated only the last two days of the studies. These, as already stated, were by-passed except during the warm summer months. The effluent from the contact beds is low in suspended solids, having an average of 17 parts per million, with a maximum of 28. The oxygen demand, both one and five days, taken with the high stability as shown by the methylene blue test, and the continued presence of nitrates, indicate an effluent satisfactory for the dilution requirements of the receiving body of water. With the additional purification effected by the intermittent filters during warm weather, no nuisance should be expected.

Even disregarding the upward trend of building costs since this plant was constructed, the capital investment in this plant can not be considered a fair figure for reproduction value. This is due to the fact that expenditures incurred in modifying the original plant have been charged to the capital account, whereas the actual increase in capital value is less than the charges so made. In addition, other expenditures charged to the capital account have included work rightly belonging to maintenance.

The total cost of the original plant in 1909 was $92,993.43. Since then $76,310.50 has been expended on modifications and repairs, making a total of $169,303.93.

The total cost of maintenance for the calendar year 1919 was $5,121.99. This includes an item of $480 for part-time services of one man at the old septic tank of the low-level sewerage system. The gross expenditures are itemized in the following table:

TABLE No. 20.—*Maintenance costs at Alliance, Ohio, for the year 1919.*

Personal services, low-level septic tank	$480.00
Personal services, main-treatment plant	3,604.19
Power and fuel	713.32
Boat hire	1.60
Machinery supplies	17.67
Light	9.50
Maintenance of buildings	25.68
Sewers	12.27
Retaining wall	84.00
Machinery repairs	167.36
New equipment	6.40
Total	5,121.99

No clerical work is charged against the sewage-treatment plant. This expense is carried by the departments in which the clerks are employed. Depreciation is disregarded, and interest on bonds issued to build and remodel the plant is not charged to the operation costs of the plant. There are $224,000 of such bonds drawing interest at 5 per cent, or a total annual charge of $11,200. The maintenance cost for 1920 will be higher than that given in the above table, due to general increases in salaries, wages, and materials.

With an average daily flow of 2.62 million gallons per day, the cost of treatment per million gallons on the basis of the above table is $5.36. If the interest on bonds is included, as it properly should be, this figure is raised to $17.07. It is not possible to give any fair figure for the initial construction cost on the basis of million gallons treated daily, because, as already stated, the available construction costs are clouded by remodeling, repair, and maintenance expenditures.

II. Atlanta, Ga.

Atlanta has three sewage-treatment plants, Intrenchment Creek, Peachtree Creek, and Proctor Creek. All were included in the engineering survey, which covered the period August 7 to 14, 1920, inclusive. In the laboratory work, however, only the first two plants were studied, because the Proctor Creek plant was not in proper condition for operation, and it was realized that any results obtained would not be representative. The laboratory studies were conducted about a month after the engineering survey, September 2 to 17.

Inasmuch as the two plants are so similar in design and operation, differing principally in capacity or the number of units of the various treatment devices, they are both included in one discussion in this section of the report.

Atlanta is a city of 200,616 population (1920 census), located in the northwest part of Georgia. As is common in this section of the country, the population is about half white and half colored. The city is the largest and one of the most important cities of the Southern States. With splendid railroad facilities, it acts as a receiving and shipping point for a large southern area and is often called the "Gateway to the South," or the "New York of the South." Its industries comprise many large and varied types of plants.

The larger part, 62 per cent of the total mileage of the sewerage system, is built on the combined system. The remaining 38 per cent, constructed on the separate system, discharges into the main outfall sewers of the combined system, thus largely eliminating, so far as treatment is concerned, any advantages of the separate system.

The total population tributary to the treatment plants is estimated at 130,000, but a large number included in this figure are only indirectly connected through privies, the contents of which are dumped into the sewers as night soil. Of the 130,000, the Peachtree Creek plant serves 75,000, Intrenchment Creek 30,000, and Proctor Creek 25,000. Sewage from some isolated sewered areas not yet tributary to any treatment plant is discharged into convenient streams.

The topography is such that natural drainage areas discharge in different directions. The city is on a divide, part draining to the Atlantic Ocean and part to the Gulf of Mexico. The lateral and trunk sewers of each drainage area discharge into main interceptors for that area. There are four main interceptors: 1. An open channel running northwest to the Peachtree Creek treatment plant. 2. Twin 9 by 13 foot concrete interceptors about 3 miles long, running northeast, also to the Peachtree Creek plant. 3. A 13-foot and a 12 by 9 foot egg-shaped interceptor about 3 miles long, running southeast, to the Intrenchment Creek plant. 4. A 14-foot interceptor about 2½ miles long, running northeast, to the Proctor Creek plant.

Each interceptor discharges into a natural water course, where the dry weather flow drops through a bar screen at the end of the interceptor to a 4-foot outfall sewer, which carries the sewage to the treatment plant. The two 4-foot outfalls to the Peachtree Creek plant join into one 4-foot sewer before reaching the plant. These sewers are large enough to carry the normal dry weather flow, but at times of storms only a relatively small portion of the discharge from the interceptors can be carried in them. The excess passes over the screen to the natural water courses.

As a rule, after every heavy rain the screens are raked and the screenings, mostly brush, sticks, etc., left below the screens to be washed downstream by the next heavy storm.

Infiltration was stated to be appreciable in both types of sewers. It is probably sufficient to have some material effect upon the operation of the treatment plants. The normal dry weather flow averages around 160 gallons per capita per day, with a water consumption around 115 gallons. Infiltration is therefore a factor, even during dry weather.

The sewage from a small district served by sanitary sewers is pumped into the interceptor. This pumping station was built to operate automatically. The equipment consists of two Worthington vertical centrifugal pumps with 4-inch suctions and 3-inch discharge, rated at 300 gallons per minute, shaft connected to two 10-horsepower General Electric Co. motors. These operate intermittently, controlled by floats in the suction well. The static head of discharge is 40½ feet. This plant is not operated a considerable portion of the time, the sewage by-passing to a near-by stream.

Grades throughout the system are adequate. Those on trunk sewers vary from 0.3 to 1.0 per cent and on laterals from 1 to 12 per cent. Sewer flushing is carried on regularly. All sewers have flushing manholes with 2-inch water connections direct from the city mains. These manholes are so arranged that the outlet can be closed while the manhole is filled with water, which is released into the sewer through an 8-inch valve. In addition to this artificial flushing the majority of the sewers receive a thorough cleaning flush at times of heavy storms.

No detailed information of the lengths of the various sizes of sewers was available. The total mileage on January 1, 1920, was 333.6, of which about 208 miles is of the combined type and 125 of the separate type.

As the sewerage system of Atlanta is about 62 per cent combined and 38 per cent separate, the raw sewage is more nearly typical of combined than of separate sewage.

That received at both of the plants surveyed is typical of combined sewage, with its domestic sewage character during dry weather and its storm sewage character during wet weather. The rains in Atlanta are likely to be very intense and the run-off is rapid, so that the change in character of the sewage is extremely marked and sudden.

Industrial wastes are not considered to have much if any effect upon the operation of the treatment plants studied. With the exception of a small amount from a steel plant, practically no wastes are discharged into the sewers tributary to the Peachtree Creek plant. The Intrenchment Creek plant at times receives an alkali cotton scouring waste in sufficient quantity to give the sewage a distinct reddish color, but it is not believed by Mr. C. C. Hommon, supervising chemist, that treatment processes are noticeably affected by it.

The sewage is received at both plants in a fresh condition, containing, as a rule, at the Peachtree plant a trace of dissolved oxygen. The color, except as noted above, is the typical whitish gray during dry weather and muddy brown at times of storms.

Floating material and solids caught on the screens are also normal, consisting of matches, fecal matter, sticks, leaves, rags, dead animals, etc.

The volume of sewage received at the two plants surveyed was not definitely known. During the war, 1917 to 1920, comparatively little attention or supervision was given to the plants, and the flow-measuring devices had been inoperative for an extended period previous to the survey. It was estimated, however, that the dry-weather flow to the Intrenchment Creek plant varied from 2½ to 6 m. g. d., averaging 5 m. g. d., and that to the Peachtree Creek plant varied from 8 to 16 m. g. d., averaging 12 m. g. d.

Previous to 1912 natural watercourses were used for the disposal of untreated sewage, resulting in an intolerable condition of pollution and nuisances. During that year the first treatment plant serving the west and northwest part of the city was installed. This was followed in 1913 and 1914 by the installation of two more plants for the major portion of the city. All plants were designed by Messrs. Hering & Fuller and are, with the exception of size and a few minor details, identical.

There have been no important modifications made since the plants were constructed. They are operating now as when first put in service, with the exception that the use of certain devices has been discontinued as unnecessary.

The 4-foot outfall sewers discharge into receiving chambers at the plants and then through coarse bar screens into one of the grit chambers. From the grit chambers the sewage flows to the Imhoff tanks, 30 at the Peachtree Creek plant and 21 at the Intrenchment Creek plant. These are arranged in units, each having three tanks, operating in series. They are of the circular type with rectangular flow chambers extending over the three separate tanks each with its own

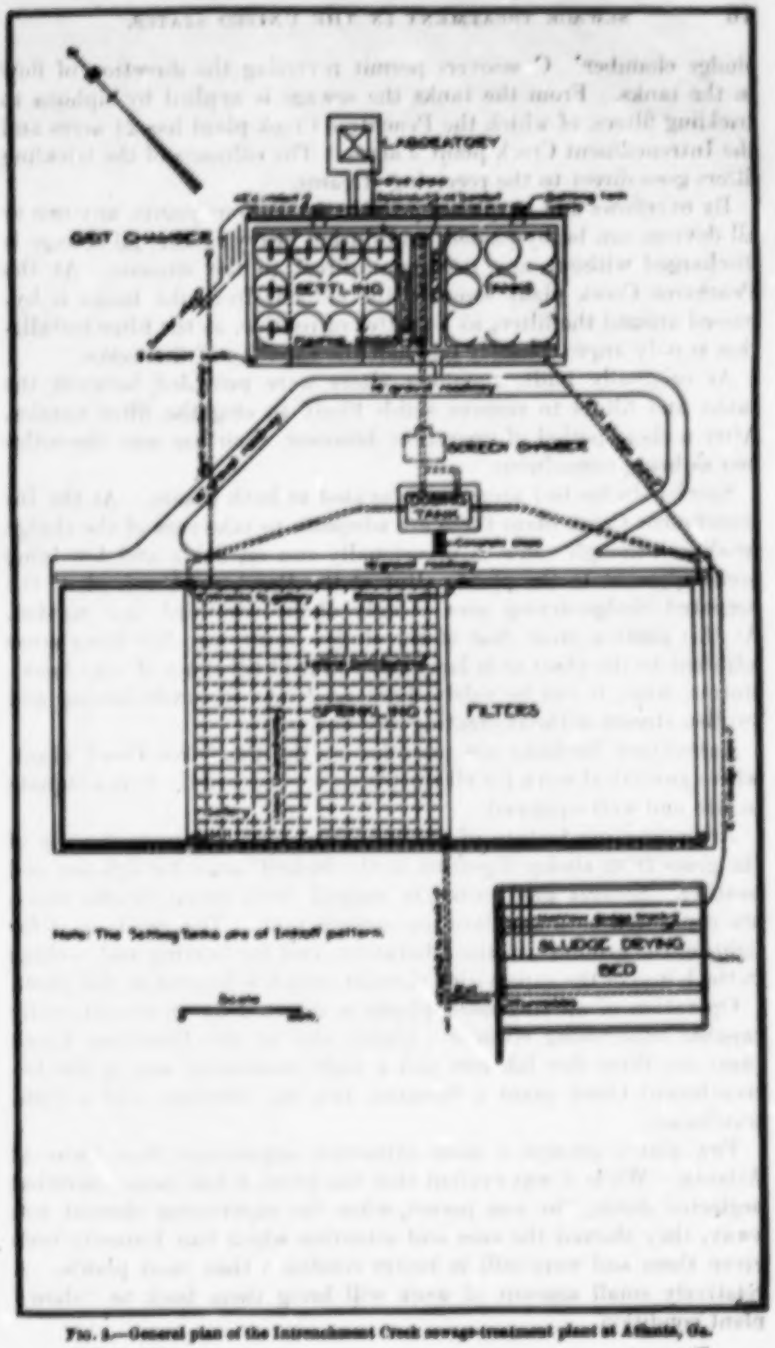
LABORATORY
GRIT CHAMBER
SETTLING
TANKS
SCREEN CHAMBER
DOSING
TANK
SPRINKLING
FILTERS
SLUDGE DRYING
BED
Note: The Settling Tanks are of Imhoff pattern.
Scale

FIG. 3.—General plan of the Intrenchment Creek sewage-treatment plant at Atlanta, Ga.

sludge chamber. Crossovers permit reversing the direction of flow in the tanks. From the tanks the sewage is applied by siphons to trickling filters, of which the Peachtree Creek plant has 2½ acres and the Intrenchment Creek plant 2 acres. The effluents of the trickling filters goes direct to the receiving streams.

By overflows and by-passes provided at various points, any one or all devices can be by-passed, and during heavy storms all sewage is discharged without any treatment direct to the streams. At the Peachtree Creek plant some of the effluent from the tanks is by-passed around the filters as a matter of routine, as the filter installation is only approximately one-half the capacity of the tanks.

As originally built, roughing filters were provided between the tanks and filters to remove solids likely to clog the filter nozzles. After a short period of operation, however, their use was discontinued as being superfluous.

Special sludge bed areas are provided at both plants. At the Intrenchment Creek plant these are adequate to take care of the sludge produced, though some is occasionally run on fields and low-lying areas adjacent to the plant. But at the Peachtree Creek plant the prepared sludge-drying area is only about one-third that needed. At this plant a great deal of the sludge is run into low-lying areas adjacent to the plant or is lagooned and held till times of very heavy storms, when it can be safely discharged into the swift-flowing and swollen stream without creating any nuisances.

Laboratory facilities are provided at the Peachtree Creek plant, where analytical work for all the plants is conducted. It is adequate in size and well equipped.

An interesting feature of the Peachtree Creek plant is the use of the gases from sludge digestion in the Imhoff tanks for lighting and heating. Several gas vents are capped with metal drums which are connected to a standard gas-storage tank. The gas is used for lighting the grounds, in the laboratory, and for heating and cooking in the house of the supervising chemist, which is located at this plant.

Operation of all treatment plants is directed by an exceptionally capable supervising chemist. Under him at the Peachtree Creek plant are three day laborers and a night watchman and at the Intrenchment Creek plant a foreman, two day laborers, and a night watchman.

Few plants present a more attractive appearance than those at Atlanta. While it was evident that the grounds had been somewhat neglected during the war period, when the supervising chemist was away, they showed the care and attention which had formerly been given them and were still in better condition than most plants. A relatively small amount of work will bring them back to "show" plant condition.

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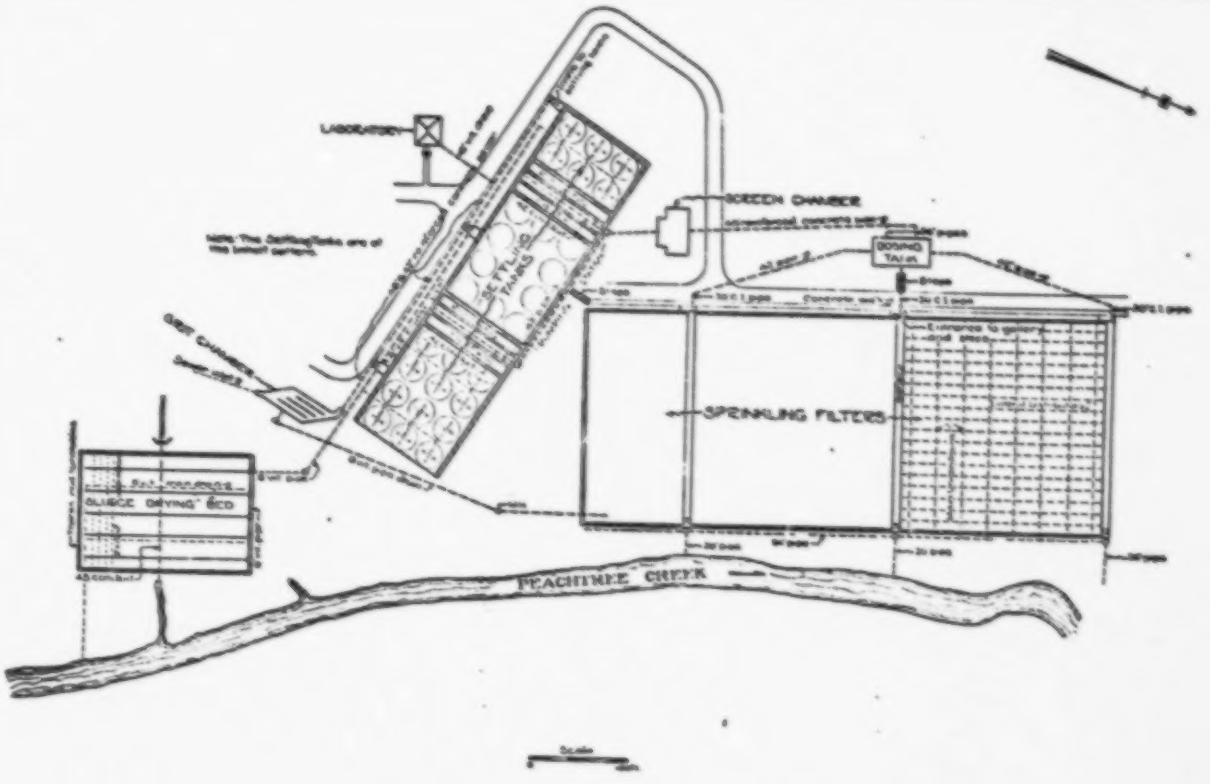
LABORATORY
Note: The Settling Tanks are of the Imhoff pattern.
SETTLING TANKS
GRIT CHAMBER
SCREEN CHAMBER
DOSING TANK
Entrance to gallery and pipes
SPRINKLING FILTERS
SLUDGE DRYING BED
PEACHTREE CREEK
Scale

Fig. 4.—General plan of the Peachtree Creek sewage-treatment plant at Atlanta, Ga.

The results of the chemical analyses made at the Intrenchment Creek plant are contained in the following table:

TABLE No. 21.—*Results of chemical analyses at the Atlanta Intrenchment Creek sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.			Settleable solids, 2 hours, c. c. per liter.[1]			Oxygen consumed 30' in boiling water.			Alkalinity as $CaCO_3$ by M. O.			Ether soluble matter 24-hour comp. raw.	Chlorine as chlorides.		
	Raw.	Effluent Imhoff tank.	Effluent trickling filters.	Raw.	Effluent Imhoff tank.	Effluent trickling filters.	Raw.	Effluent Imhoff tank.	Effluent trickling filters.	Raw.	Effluent Imhoff tank.	Effluent trickling filters.		Raw.	Effluent Imhoff tank.	Effluent trickling filters.
Sep. 2	98	30	19	3.1	0.6	Tr.	33	30	3.0	84	90	78	29	101	97	102
3	146	70	61	3.0	.3	Tr.	29	17	11.0	88	90	98	181	98	104	102
5	98	104	48	1.3	.1	Tr.	40	27	19.0	68	88	40	210	98	90	99
6	102	36	35	3.0	.3	Tr.	34	15	11.0	72	72	24	182	98	84	98
8	90	48	40	.5	.2	Tr.	25	20	6.0	78	88	28	88	78	90	92
10	114	42	48	2.0	1.4	Tr.	28	16	11.0	81	81	40	228	98	98	98
11	84	20	48	1.2	.3	Tr.	27	24	12.0	78	80	40	61	101	104	102
14	98	82	68	4.5	2.1	0.9	37	24	14.0	80	78	32	28	98	98	94
15	98	66	40	2.3	.6	Tr.	46	23	11.0	80	88	52	10	94	90	91
16	112	98	32	4.0	.5	Tr.	42	14	4.0	66	78	42	30	98	97	97
17	144	54	16	1.9	.5	Tr.	....	....	....	....	....	....	....	....	....	....
Average	108	67	42	2.4	.6	Tr.	35	21	10.0	77	80	48	104	98	94	94

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.						Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.					Nitrogen as nitrates, effluent trickling filter.
	Raw.		Effluent Imhoff tank.		Effluent trickling filters.		Raw.	Effluent trickling filters.	Raw.		Effluent Imhoff tank.		Effluent trickling filters.	
									Per cent. concentration.					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.			20	40	20	40	100	
Sept. 2	16	33	12	33	0	3.6	0.0	4.5	[2]216+	......	[2]216+	......	216+	1.0
3	54	78	......	18	......	2.6	.0	5.7	[2]90	......	[2]192+	......	216+	1.0
5	48	188	8	20	.6	3.9	......	6.0	[2]300+	......	[2]300+	......	300+	3.0
6	10	12	6	10	1.9	2.7	.0	5.6	113	41	336+	90	336+	......
8	8	30	4	20	4.3	5.8	.0	6.2	70	46	288+	48	288+	7.0
10	26	54	8	20	3.1	5.8	.0	5.9	75	23	240+	23	240+	2.0
11	12	52	9	28	2.3	5.2	......	4.7	41	41	90	16	216+	9.0
14	26	50	......	36	3.1	4.5	.0	4.7	41	16	66	16	144+	1.0
15	......	......	......	......	......	......	......	5.0	64	21	120+	21	120+	1.0
16	......	......	......	......	......	......	......	5.8	30	23	96+	23	96+	6.0
17	......	......	......	......	......	......	......	......	......	......	......	......	......	1.0
Average	25	63	9.2	23	2.1	4.3	......	5.4	......	......	......	......	......	3.1

[1] Tr. indicates less than 0.1 c. c.
[2] Dilution 10 per cent.

During the days covered by these analyses, there were heavy rains on the 2d, 3d, 6th, and 8th; traces on the 5th and 10th; but no rain during the remaining days of the tests. On four days, the 4th, 9th, 12th, and 13th, all sewage was by-passed to the creek. The analyses on the days the plant was operated indicated a weak sewage, probably due to dilution of storm and ground water. The suspended solids of the raw sewage is only slightly above 100 parts per million, and the 5-day oxygen demand only 67. The 1915 records at the plant, however, show an average suspended solids content of 140, which indicates that the sewage is normally stronger than indicated by the results tabulated.

The analyses in the above table show a very highly purified plant effluent with a 5-day oxygen demand of 4.3, a dissolved oxygen content of 5.6 parts per million, and a uniform retention of methylene blue color.

The results obtained at this plant as well as those at the Peachtree Creek plant are not considered as representative of normal dry weather conditions as those obtained from the other plants visited.

The results of the chemical analyses made at the Peachtree Creek plant are contained in the following table:

TABLE NO. 22.—*Results of chemical analyses at the Atlanta-Peachtree sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.			Settleable solids, 2 hours c. c. per liter.[1]			Oxygen consumed 30' in boiling water.			Alkalinity as $CaCO_3$ by M. O.			Ether soluble matter 24-hour comp. raw.	Chlorine as chlorides.		
	Raw.	Effluent Imhoff tank.	Effluent trickling filters.	Raw.	Effluent Imhoff tank.	Effluent trickling filters.	Raw.	Effluent Imhoff tank.	Effluent trickling filters.	Raw.	Effluent Imhoff tank.	Effluent trickling filters.		Raw.	Effluent Imhoff tank.	Effluent trickling filters.
Sept. 2	114	54	12	1.3	Tr.	Tr.	12	8	3	62	62	62	218	86	88	84
3	.....	108	59	.....	0.4	Tr.	.....	20	3	.....	64	56	.....	84	86	92
4	908	54	54	9.0	Tr.	Tr.	60	15	4	76	74	30	97	88	88	88
5	426	173	59	4.8	.3	Tr.	62	22	13	48	40	24	78	80	85	84
10	224	80	62	.9	.2	Tr.	27	13	8	68	68	26	208	80	78	70
11	158	64	69	.4	Tr.	Tr.	30	21	11	76	78	30	79	78	82	82
12	94	47	16	1.5	Tr.	Tr.	29	18	6	60	66	26	94	83	90	88
13	54	35	27	.9	Tr.	Tr.	19	11	4	68	60	24	16	81	84	86
14	98	38	21	1.8	Tr.	Tr.	30	22	7	80	102	33	22	92	90	88
15	130	44	22	1.8	Tr.	Tr.	32	17	5	64	68	40	40	90	89	91
16	160	49	30	2.5	Tr.	Tr.	46	35	16	66	77	38	34	94	92	96
17	124	68	28	2.5	.5	Tr.	39	13	4	76	72	36	32	101	95	97
Average	226	68	38	2.5	.2	Tr.	35	18	7.0	68	69	35	83	86	87	87

[1] Tr. indicates less than 0.1 c. c.

Table No. 22.—*Results of chemical analyses at the Atlanta-Peachtree sewage-treatment plant*—Continued.

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ±C.						Dissolved oxygen.		Hours to reduce M. B. at 20° ±C.					Nitrogen as nitrates, effluent trickling filters
	Raw.		Effluent Imhoff tanks.		Effluent trickling filters.				Raw.		Effluent Imhoff tanks.		Effluent trickling filters.	
									Per cent concentration.					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.	Raw.	Effluent trickling filters.	20	40	20	40	100	
Sept. 2	16	40	13	36	0.0	5.0	0.0	4.0	[1]122	......	[1]122	......	240+	1.0
3	......	......	8	18	.4	4.0	......	5.0	......	......	[1]216	......	192+	2.0
4	......	112	......	20	......	3.0	......	.0	[1]72	......	[1]192	......	192+	1.0
5	24	88	8	12	.0	2.2	.0	7.3	67	......	[1]240+	......	240+	2.0
10	5.8	24	2	4	1.7	2.3	.0	7.4	47	......	119	......	120+	1.0
11	11	36	7	30	3.0	5.8	......	6.0	22	22	22	22	96+	5.0
12	13	37	10	27	3.5	5.4	......	5.6	24	22	144	22	192+	1.0
13	3	11	3	5	2.5	4.4	.0	6.4	168+	47	168+	96	168+	6.0
14	32	68	18	30	2.0	3.7	.0	4.6	70	24	70	24	144+	1.0
15	......	......	......	......	......	......	......	5.5	46	31	46	31	120+	1.0
16	......	......	......	......	......	......	.0	5.8	70	24	96+	24	96+	2.0
17	......	......	......	......	......	......	......	5.2	......	23	......	46	72+	2.0
Average	15	52	8.5	20	1.6	3.9	......	5.7	......	......	......	......	......	2.1

[1] 10 per cent concentration.

The remarks already made concerning the results obtained at the Intrenchment Creek plant are largely applicable to the results in the above table. Heavy rains altered the character of the raw sewage, and interfered with the operation of the plant to such an extent that the results are not comparable with those obtained from the other plants. The suspended solids in the raw sewage averaged 226 parts per million due to the excessively high results for the 4th and 5th.

With the exception of rather high suspended solids results, the effluent from the trickling filter is exceptionally good. The 5-day oxygen demand is only 63 per cent of the dissolved oxygen content, and methylene blue samples, even those kept for ten days, were not decolorized.

It is difficult to secure cost data from various plants in such form that they will admit of comparison. At some only a lump-sum total for the whole plant is available, at others detailed unit prices can be obtained, and occasionally the cost of different devices are on record. Unit prices are too detailed to be included in a report of this nature. At Atlanta it was possible to get the total cost of each plant and also the lump sum of the main treatment devices. The engineering cost, however, was totaled for all three plants, and has been arbitrarily divided between the plants in the ratio of their total costs exclusive of land.

The following table has been arranged, covering this data for the two plants surveyed;

TABLE No. 23.—*Cost of construction of the Intrenchment Creek and the Peachtree Creek sewage-treatment plants at Atlanta, Ga.*

Item.	Intrenchment Creek.		Peachtree Creek.	
	Cost.	Remarks.	Cost.	Remarks.
Year completed		1914		1913.
Land	$19,580		$24,475	
Grit chambers	2,500		2,750	
Imhoff tanks	31,900	21 tanks rated 5 m. g. d.	39,200	30 tanks rated 10 m. g. d.
Dosing tanks	5,000		5,000	
Trickling filters	85,784	2 acres	83,838	2½ acres.
Sludge beds	6,000		9,500	
Laboratory			2,000	
Roughing filters	12,000	Not operated	17,500	Not operated.
Engineering	29,200		35,300	
Other items	27,709		50,743	
Total	221,673		270,306	

Very little data on maintenance costs were available. In fact the only definite figure obtainable was that of $10,919.66 for supervision and labor for all three plants for 1919. During this year the supervising chemist was serving in the Army, and had returned only a week previous to the engineering survey, so that the above figure does not represent normal conditions. At the time of the survey, the salary of the supervising chemist had not been fixed, labor was receiving $75 to $80 per month, night watchman $77.50, and the foreman at the Intrenchment Creek plant $75, plus a house.

III. BALTIMORE, MD.

The engineering survey of the sewage-treatment plant at Baltimore, Md., was made July 19 to 27, 1920. The laboratory work followed a little over a month later, August 24 to September 4.

Baltimore is a city of 734,000 population (1920 census) situated at the head of Chesapeake Bay. It is an important railroad center, and one of the large ports for foreign trade on the Atlantic coast. In addition, there are located within and adjacent to the city many large industrial plants of varied types.

Previous to 1912 most of the sewage was collected in cesspools, which were periodically cleaned out. All drainage from houses except toilet waters was carried, for the most part, in open gutters, to nearby drains, which emptied into the harbor, and small open streams flowing through the city. This practice created an intolerable nuisance in the harbor.

The present sewerage system, built since 1906, is of the separate type. It is divided into two sections the high level and the low level. The high-level sewage is collected in an interceptor, which discharges into a gravity outfall sewer to the treatment plant. The low-level sewage flows in two interceptors to a pumping station, where it is lifted to the outfall sewer carrying the high-level sewage. Each of these sections of the system contributes about one-half of the total volume of sewage.

The pumping station is located near the heart of the down-town business section. Sewage before entering the pumps is first passed through hoisting-cage screens and then through one stationary bar screen. There are four cage screens, which are placed so that the sewage has to pass through at least two of them. It is pumped by three 27½ m. g. d., Bethlehem steel vertical, triple-expansion, plunger, crank, and fly-wheel pumps. A peculiar feature in the design of this station is the total omission of any overflows or by-passes. A relatively short shutdown of the pumps would result in disastrous flooding of the surrounding business section with sewage. The average pumpage is 27 to 30 m. g. d., except on Sundays when it drops to about 24 m. g. d.

While the effects of storms are felt at the treatment plant, the infiltration through leaky sewers and manhole covers is very moderate. Sewage flows at the plant also give no indication of excessive infiltration. The absolute maximum rate of flow for the year 1919 was less than twice the average daily flow for the entire year.

Grades of all sewers are computed to give a minimum velocity of 3 feet per second, lateral sewers under 18 inches averaging 2 to 3½ per cent.

For cleaning and flushing it was formerly the practice to make all terminal manholes within 150 feet of a water main into flushing manholes. These have a 1½-inch connection to the water mains through which the manhole is filled, and the water is then released through a valve into the sewer. The terminal manholes that are now being built are not being provided with flushing connections. Some other manholes, besides the terminal ones, also have water connections, and, in addition, there are three flush tanks on the system.

It was not possible to secure the mileage for the various sizes of sanitary sewers, but the total to January 1, 1920, was 606.7 miles, plus or minus 1 to 2 per cent. The total number of connections to the sewers, as of the same date, was 101,000. This figure corresponds to an estimated connected population of 520,000, giving 5.2 persons per connection.

The raw sewage received at the treatment plant is typically domestic, generally stale but occasionally containing a trace of dissolved oxygen. The observed color was a whitish gray, and the floating material and other suspended solids consisted of the usual materials, pieces of soap and fecal matter, sticks, paper, fruit and vegetable skins, etc.

While there are a large number of varied types of industries tributary to the sewers, such as slaughterhouses, canneries, steel mills with pickling plants, dye, drug, and flavoring-extract factories, soap works, and breweries, no evidence of industrial wastes was observed in the sewage. The wastes from the industries are small compared with the total flow of sewage. It was stated that occasionally fresh entrails, etc., from slaughterhouses, and an excessive amount of fruit and vegetable skins during the canning season evidenced the entrance of these wastes into the sewers, but it is not felt that any of the wastes affect the operation of the treatment devices.

Sewage received at the plant is measured by Venturi meters. The average for the entire year 1919 was 55 m. g. d. For the year mentioned, the average maximum daily rate of flow was 72 m. g. d., with an absolute maximum of 106.1. The average minimum daily rate was 36.7 m. g. d. These figures confirm statements already made that the sewage contains but little storm or ground water.

The sewage treatment plant, as well as the sewerage system, was built by the Baltimore Sewerage Commission under Calvin Hendricks, its chief engineer, with the cooperation and advice of various consulting engineers. Operation of the treatment plant was started in the latter part of 1911, and since that time only minor changes have been made in the construction details.

The outfall sewer at the plant inlet is horseshoe shaped, and discharges into the screen chambers. Half of the sewage has been screened at the pumping station; but, as it is mixed with the unscreened sewage from the high-level sewerage system in the outfall sewer, it is necessary to pass the entire flow through the screens at the treatment plant. From the screens the sewage passes through recording Venturi meters to the sedimentation tanks.

The tank installation consists of 3[3] large, rectangular, hydrolytic tanks, and 28 circular radial-flow Imhoff tanks. The hydrolytic tanks are regularly operated two in parallel, with the third idle or being cleaned. These tanks were treating, at the time of the survey, about 95 per cent of the entire flow. The Imhoff tanks were designed for a capacity of ½ m. g. d., each, but only five or six were in operation.

Considerable difficulty has been experienced in the operation of the Imhoff tanks. It is believed, however, that the failure of the tanks to operate satisfactorily at Baltimore is due to local factors of design and situation, and not to the breaking down of the theory of Imhoff tank treatment. This feeling finds expression at the Baltimore plant itself. The adoption of the German system of a large number of relatively small units instead of a few with greater individual capacity

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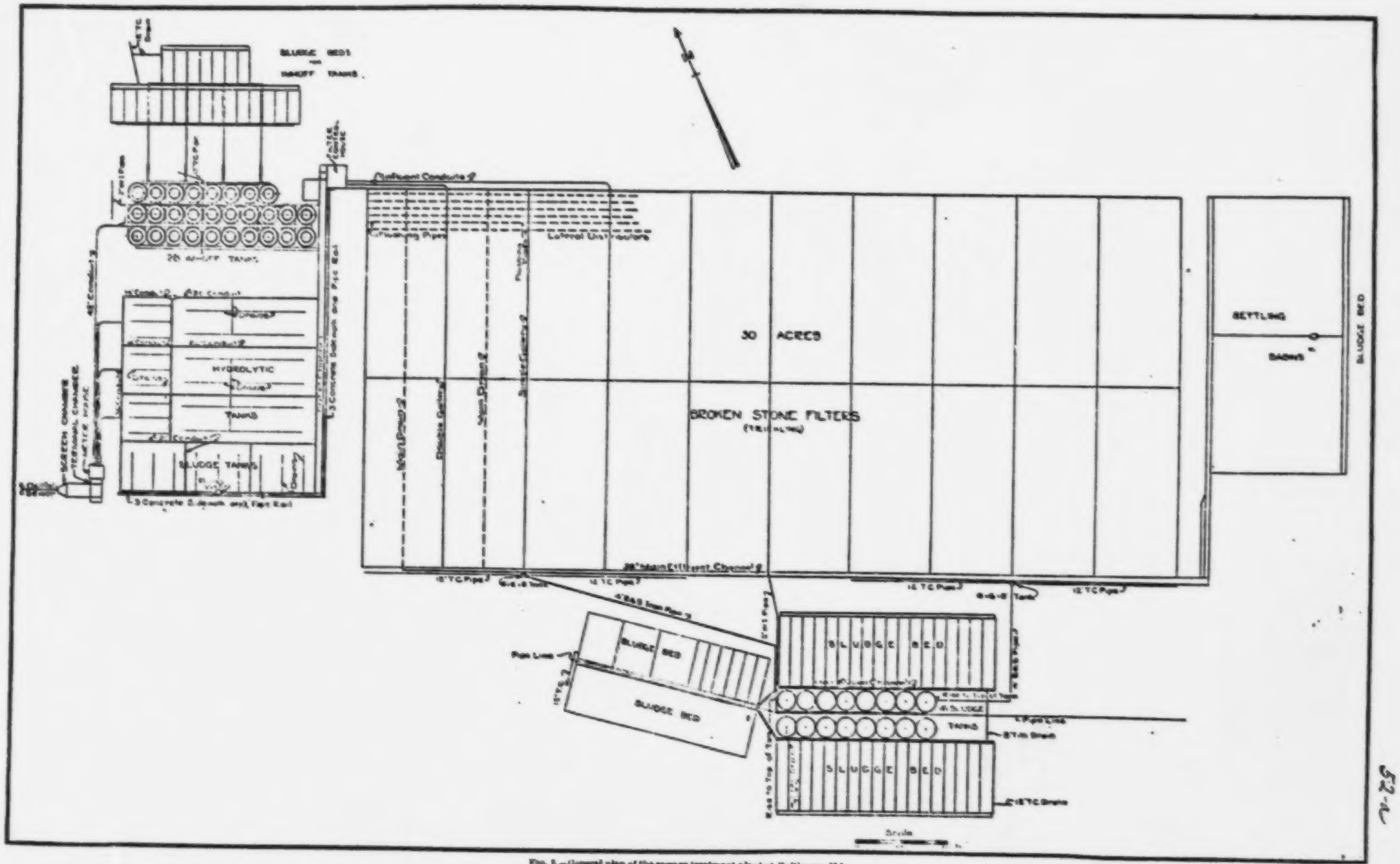
[3] Since the survey a fourth tank has been added.

52-a



SLUDGE BEDS
HAKEFF TANKS
FILTER CONTROL HOUSE
Effluent Conduits
20 HAKEFF TANKS
Flushing Pipes
Lateral Distributors
HYDROLYTIC
TANKS
SLUDGE TANKS
SCREEN CHAMBER
TERMINAL CHAMBER
Concrete Sidewalk and Pipe Rail
Concrete Sidewalk and Pipe Rail
Main Drain
Double Gallery
Main Drain
Single Gallery
30 ACRES
BROKEN STONE FILTERS
SETTLING
BASINS
SLUDGE BED
Main Effluent Channel
12" T.C. Pipe
12" T.C. Pipe
12" T.C. Pipe
12" T.C. Pipe
Tank
Pipe Line
SLUDGE BED
SLUDGE BED
SLUDGE BED
SLUDGE
TANKS
SLUDGE BED
Pipe Line
T.C. Drain
Scale

Fig. 5.—General plan of the sewage-treatment plant at Baltimore, Md.

35013—13. (Face p. 52)

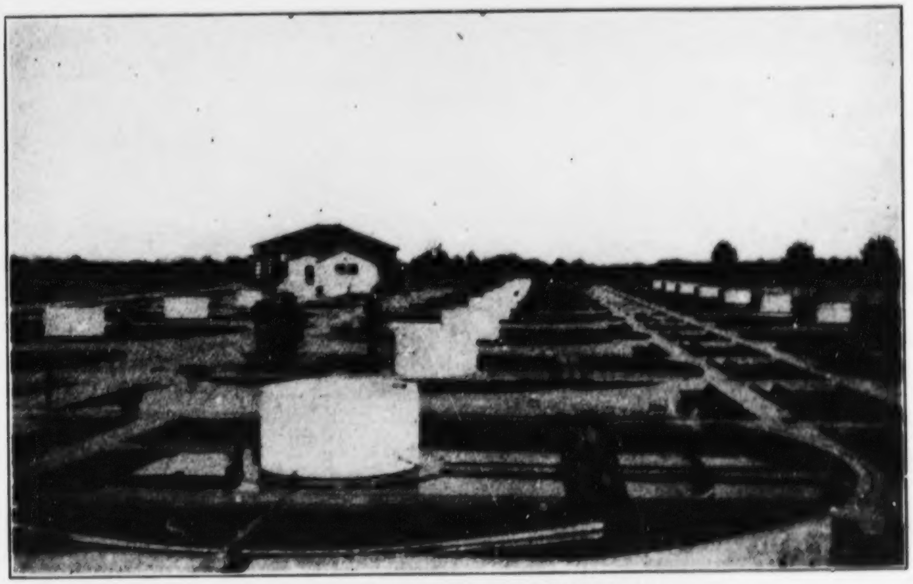


FIG. 6.—IMHOFF TANKS AT BALTIMORE, MD.

is undoubtedly the cause of a large part of the dissatisfaction with these tanks at Baltimore. Another serious though purely local difficulty in the operation of these tanks at Baltimore is the fact that the Imhoff tanks require a slightly greater head for operation than the hydrolytic tanks which are run in parallel with them. As a result, the sewage during a part of the time when the flow is low, about four hours a day, all passes into the hydrolytic tanks, automatically throwing the Imhoff tanks out of operation. In addition, as the sewage flow increases, but before it will pass to the Imhoff tanks, the head in the outlet channels of the hydrolytic tanks builds up sufficiently to back into the outlet channels of the Imhoff tanks.

The effluent from the sedimentation tanks is passed through fine screens to remove solids of sufficient size to clog nozzles on the filter beds. In this way the number of nozzles requiring cleaning has been materially reduced. The screens, of which three were in operation at the time of the survey and a fourth being installed, are of the revolving drum type, the sewage entering the inside of the drum. They are covered with a 24-mesh Monel metal wire screen. Cleaning is done by a line of jets playing continually across the screen near the top point of revolution. The jets are fed with the final plant effluent which is pumped to an elevated tank to provide pressure. The screenings are carried by the wash water to an Imhoff tank for sedimentation.

The effluent from the screens is applied to trickling filters through butterfly valves operated by a friction drive actuated by a small motor. There are 10 units of trickling filters, of 3 acres each. Of these an average of 12 to 24 acres, depending on the volume of flow, are used regularly, the excess acreage being dosed about one hour daily to keep it in condition. A rather unusual feature in the operation of these filters is the fact that the underdrainage and part of the filtering material itself is submerged during a part of each day. This results from raising the flow line in the secondary sedimentation tanks following the filters.

The filter effluent is passed through two secondary sedimentation tanks, and below these tanks there is available head to operate a hydroelectric plant which provides the power used in the operation of the entire treatment plant. Final disposal is through submerged outlets from two 5-foot conduits extending 2,500 feet into Back River.

Sludge from the Imhoff tanks is applied directly to drying beds, but that from the hydrolytic tanks is pumped to sludge digestion tanks. In practice a hydrolytic tank is operated for a period, then shut down and allowed to rest for a couple of days. The liquor between the scum and the sludge is drawn off, leaving the scum and sludge to be pumped to the digestion tanks. The digestion tank installation consists of 3 rectangular and 16 circular tanks. After digestion, the sludge is dried on beds.

A part of the sludge from the beds is delivered in small industrial cars to a drying plant located adjacent to the treatment plant on city property. Here it is prepared for use as a filler for fertilizers.

There are no overflows or by-passes, designed as such, whereby the sewage can be discharged untreated or partially treated into Back River.

Laboratory facilities are exceptionally good, both as regards space and equipment. They are housed in the administration building, a large and attractive two-story and basement structure. The basement contains a well-equipped machine and repair shop. The superintendent's offices are on the first floor, and the laboratories, offices, storerooms, etc., occupy the second floor.

The operation of the plant is under a superintendent, who has a force, including the laboratory personnel, of about 25 men. The laboratory work is directed by a chief chemist, who has under him an assistant chemist and an assistant bacteriologist.

The value of an attractive physical appearance about the plant is appreciated by the city officials. The first impression at the entrance to the grounds is very pleasing, and it is evident that every effort is made to have the visitor carry this impression away with him after his inspection of the plant.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 24.—*Results of chemical analyses at the Baltimore (Md.) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.					Settleable solids, 2 hours c. c. per liter.[1]				Oxygen consumed 30' in boiling water.				Alkalinity as $CaCO_3$ by M. O.				Ether soluble matter 24-hour comp. raw.	Chlorine as chlorides.			
	Raw.	Effluent of tanks.	Effluent trickling filters.	Effluent secondary sedimentation tank.	Raw supernatant.	Raw.	Effluent of tanks.	Effluent trickling filters.	Effluent secondary sedimentation tank.	Raw.	Effluent of tanks.	Effluent trickling filters.	Effluent secondary sedimentation tank.	Raw.	Effluent of tanks.	Effluent trickling filters.	Effluent secondary sedimentation tanks.		Raw.	Effluent of tanks.	Effluent trickling filters.	Effluent secondary sedimentation tank.
Aug. 24	300	128	60	56	58	3.8	0.8	.....	.....	42	33	17	12	144	144	76	76	58	85	90	90	85
25	162	.....	.....	44	56	4.2	.....	.....	Tr.	26	.....	.....	14	132	156	80	80	52	90	90	90	95
26	256	116	46	48	84	4.0	.3	0.1	Tr.	55	29	10	12	144	150	70	74	56	90	90	80	90
27	132	116	74	36	58	2.0	.8	Tr.	Tr.	34	36	16	10	120	144	68	54	36	78	88	72	55
28	144	120	80	46	36	2.5	.6	Tr.	Tr.	40	34	22	10	120	120	64	44	38	96	96	90	65
29	88	84	26	22	24	2.5	.5	Tr.	Tr.	31	30	14	11	112	132	72	56	33	78	88	85	78
30	146	96	36	42	28	1.7	.3	Tr.	Tr.	32	30	10	13	138	128	58	52	30	90	98	75	78
31	128	108	28	54	34	2.0	.5	Tr.	Tr.	46	44	12	13	116	164	56	60	36	75	105	70	65
Sept. 1	188	112	42	28	56	3.0	.7	Tr.	Tr.	54	43	13	12	168	144	60	64	48	88	95	65	68
2	146	84	20	16	28	2.5	.3	Tr.	Tr.	40	45	12	12	124	148	52	52	30	80	97	60	66
3	192	118	28	20	32	2.5	.5	Tr.	Tr.	52	29	10	12	152	152	48	60	28	98	92	60	65
4	124	96	46	66	44	4.5	.5	Tr.	Tr.	54	31	13	19	162	140	50	48	36	78	88	62	98
Average	159	107	46	41	45	2.9	.6	Tr.	Tr.	43	36	14	12	136	144	63	60	40	88	93	74	76

[1] Tr. indicates less than 0.1 c. c.

TABLE No. 24.—*Results of chemical analyses at the Baltimore (Md.) sewage-treatment plant*—Continued.

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.								Dissolved oxygen.			Hours to reduce M. B. at 20° ± C.				Nitrogen as nitrates.	
	Raw.		Effluent tanks.		Effluent trickling filters.		Effluent secondary sedimentation tank.		Raw.	Effluent trickling filters.	Effluent secondary sedimentation tank.	Raw.	Effluent tanks.	Effluent trickling filters.	Effluent secondary sedimentation tanks.	Effluent trickling filters.	Effluent secondary sedimentation tank.
												Per cent concentration					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.				10	10	100	100		
Aug. 24...	68	144	68	138	2.0	12.0	5.0	11	0.0	6.8	6.2	48	48	240+	240+	6.0	6.9
25...	68	164	60	156	5.0	20.0	......	9	1.1	4.8	4.6	72	23	23	240+	2.4	3.2
26...	82	104	64	144	5.2	16.0	4.2	11	.9	6.7	5.7	48	48	240+	240+	6.8	8.0
27...	48	104	60	104	4.5	16.0	3.2	6	.0	5.0	5.2	72	72	240+	240+	5.6	4.8
28...	48	88	52	116	6.5	22.0	3.5	7	.0	4.6	5.1	48	48	216+	216+	3.2	3.6
29...	44	92	44	104	5.0	11.0	3.0	5.5	.0	5.4	5.8	72	72	192+	192+	0.4	1.0
30...	60	120	60	108	4.5	9.5	4.0	7.5	0	4.4	4.7	120+	120+	168+	168+	4.8	2.8
31...	68	136	92	160	2.5	6.5	5.0	10	0	4.3	4.8	120+	120+	144+	144+	2.4	1.4
Sept. 1...	56	96	84	108	3.6	......	4.2	......	.0	4.5	5.0	72	72	120+	120+	0.0	0.0
2...	52	92	68	108	3.1	......	3.5	......	.0	5.3	4.7	72	96	96+	96+	1.8	1.2
3...	......	......	......	......	......	......	......	......	.0	5.4	4.9	48	48	72+	72+	......	......
4...	......	......	......	......	......	......	......	......	.0	4.9	5.9	48	48+	48+	48+	......	......
Average	59	120	63	125	4.1	14	3.9	8.3	0.2	5.1	5.2	......	......	......	......	3.3	4.2

The results of the analyses of the raw sewage are very close to the average of those obtained from all the raw sewages studied in this investigation. This statement is very clearly evidenced in Table No. 45, which has been arranged as a summary table for the raw sewages of the plants visited. The difference between individual results and the average is entirely normal.

If all the results of the tank effluent were included in the average, practically no difference could be found between it and the raw, except in a decided increase of suspended solids. On August 25 one of the hydrolytic tanks was unloading badly, raising the suspended solids content of the settled sewage to 1,400 parts per million. Considering the short period covered by the studies, it is obviously unfair to average in this sample.

Although there is only a 33 per cent reduction of suspended solids and a 16 per cent reduction of oxygen consumed, while the 5-day oxygen demand and the methylene-blue results are practically identical for the tank's effluent as for the raw waste the two hours settling in Imhoff cones show a 79.3 per cent removal of those solids capable of settling. Since these tanks are used as plain sedimentation tanks, the Baltimore officials base their efficiency primarily upon the removal of settleable solids and change from a dirty to a clean tank upon this basis.[4]

The treatment following the tanks, however, is very effective. The plant as a whole removes 118 parts per million of suspended solids, but only 52 parts is removed by the tanks as against 66 parts by subsequent devices. Judging the results by the analyses there are no grounds for criticizing the character of the final effluent, which contains in the form of dissolved oxygen nitrates and nitrites more than enough oxygen to completely satisfy its 5-day oxygen demand. None of the 12 samples of the final effluent, when incubated with methylene blue, were decolorized, though some of them were held for 10 days.

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[4] Comment by Milton J. Ruark, division engineer of sewers.

The construction costs of the treatment plant are contained in the following table.

TABLE No. 25.—*Construction costs of the Baltimore, Md., sewage treatment plant.*[a]

Land	$200,000.00
Clearing and grading	160,562.17
Hydrolytic tanks	239,938.18
Imhoff tanks	78,400.00
Trickling filters	1,519,336.55
Secondary sedimentation tanks	50,000.00
Outlet and submerged conduits	103,675.75
Sludge digestion tanks	128,623.95
Sludge drying beds	43,637.82
Laboratory, power house, roads, etc	202,753.45
Total	2,726,927.87

The above table does not include engineering and administrative expenses. These two items are estimated to be $218,472.78. Very little has been spent in reconstruction or modification work. It is estimated that $25,000 will cover all such expenditures.

The operating and maintenance costs for the year 1919 may be summarized as follows:

Salaries	$19,728.28
Wages	39,468.80
Materials and supplies	8,915.62
Total	68,112.70

It is noted that no charge is made for depreciation or for interest on the investment. With a flow of 55 m. g. d., the above operating costs are equivalent to $3.39 per million gallons treated. Mr. G. J. Requardt in the Municipal Journal, of November 2, 1916, gives treatment costs per million gallons for the years 1912 to 1914, inclusive, and for the year October, 1914, to September, 1915. The items included in the operating costs are the same as used in this report for the year 1919. Mr. Requardt's figures show a steadily decreasing unit cost from $4.86 in 1912, to $3.58 for the year October, 1914, to September, 1915. The 1919 figure shows a still further decrease to $3.39. The reason for this continued decrease becomes evident when the volume of sewage treated during the different periods is taken into consideration. In 1912 the flow averaged only 12 m. g. d., while in 1919 it was 55 m. g. d.

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[a] Corrected to Nov. 7, 1921, by the division engineer of sewers, Baltimore, Md., and includes additions subsequent to the date of the survey.

IV. CANTON, OHIO.

The engineering survey of the sewage treatment plant at Canton, Ohio, was made June 6 to 9, 1920. The laboratory studies followed shortly afterwards, June 23, to July 2.

Canton is a city of 87,091 population (1920 census), located in the northwestern part of Ohio, on the main line of the Pennsylvania Railroad. It is an important industrial center with a variety of different types of manufacturing plants, those making iron and steel products, however, predominating.

The sewerage system is of the separate type. It was stated that no roof drains are connected to the sanitary sewers, and that the only storm or ground water reaching them is from leakage or infiltration. This is well below the average over the country, as the sewers have been laid with special care and largely in dry trenches. In addition, industrial wastes are for the most part excluded, especially those which might affect treatment processes. Occasionally, however, large amounts of oil wastes from unknown sources are received, and these seriously interfere with proper operation of the plant.

The grades are, for the most part, sufficient to provide self-cleaning velocities. Those for laterals average 0.5 to 0.6 per cent, those for the subtrunk sewers run as low as 0.2, and that for the outfall to the treatment plant is 0.1 per cent.

Cleaning and flushing is done by flush tanks or by hose or by a combination of direct water connection and flush tank. Flush tanks are installed on new sewers, but, as the flow of sewage becomes sufficient for self-cleaning, the automatic feature of the flush tanks is dispensed with, and they are turned on and off as occasion demands. Hose flushing is comparatively limited. There is no regular schedule, sewers being flushed only when they become stopped.

The total mileage of all sewers is 163, of which about 18 miles consists of 4-inch house connections. Below are listed the amounts of the various sizes of pipe included in the system.

4-inch, 109,000 linear feet. (About 90 to 95 per cent of this is house connections.)
6-inch, 189,600 linear feet.
8-inch, 439,100 linear feet.
9-inch, 5,600 linear feet.
10-inch, 35,900 linear feet.
12-inch, 8,600 linear feet.
15-inch, 38,700 linear feet.
Egg-shape, 3,300 linear feet.

The egg-shape sewer has a maximum vertical diameter of 4 feet 8 inches, horizontal diameter of 2 feet 2 inches, and invert radius of 3½ inches.

There are on record 15,737 sewer connections. Some of these are idle and a few are storm connections, but there are also a few sanitary connections not of record. The local estimate of actual active sanitary connections is 15,700.

At five points on the system overflows have been provided to take care of flows in excess of the capacity of the sewers; one is on an 8-inch line, two on 10-inch, one on an 18-inch, and one on a 20-inch. These operate probably once or twice a week, but the volume of sewage thus discharged into Nimishillen Creek is not known. In addition to these overflows, there are two by-passes whereby all the sewage can be diverted into the creek.

The raw sewage received at the plant is strictly sanitary, plus a relatively small volume of ground water from infiltration. That the infiltration is low is evidenced by the data in Table No. 26, below, which shows that the average daily flow varied less than 1 m. g. d., and the maximum and minimum were less than 2 m. g. d. apart.

There is a three-hour travel in the trunk sewer from the city to the plant. This, added to the period in city mains and laterals, is sufficient to produce some septic action. The odor on the days of inspection was that of slightly septic sewage. The suspended matter was well broken up and more or less water-logged, so that there was but little material floating on the surface.

The material caught on the screens consisted of paper, matches, fruit and vegetable skins, fecal matter, etc. There was no indication of industrial wastes, confirming the statement that all such had been eliminated from the sanitary sewers.

When still and under cover of the building over the screen and grit chambers, the color was a bluish black, but in direct light in the flume to the tanks, it was a deep gray.

The following flow readings were available for the period of one year preceding the inspection. The estimated extreme rates were 3 and 6½ m. g. d. for minimum and maximum, respectively.

TABLE No. 26.—*Volume of sewage treated at the Canton (Ohio) sewage-treatment plant.*

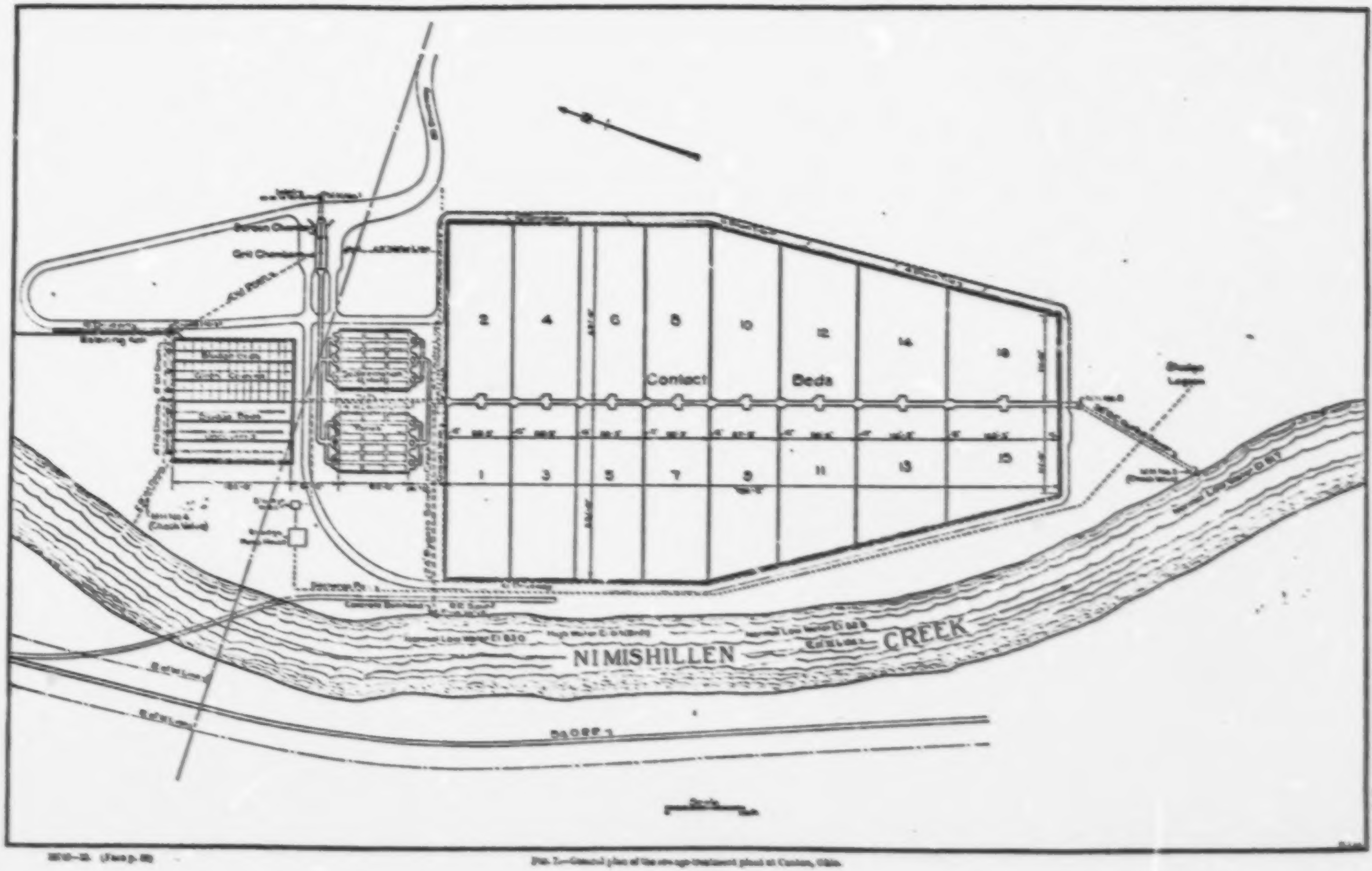
Daily flow in million gallons.	Month, 1919-20.									
	June.	July.	Sept.	Oct.	Nov.	Dec.	Jan.[1]	Feb.[1]	Mar.[1]	pr.[1]
Average for month	4.56	4.97	4.42	4.07	4.37	4.25				4.41
Maximum day for month	5.00	5.66	4.72	4.55	4.78	4.77	4.31	5.06	4.53	4.89
Minimum day for month	4.23	4.67	4.02	3.85	4.04	3.89	3.91	4.01	3.75	4.07
Remarks								10 days.	14 days.	11 days.

[1] Recording gauge not working regularly.

The treatment plant was designed by Mr. R. W. Pratt, consulting engineer of Cleveland, Ohio, in 1914, and was put in operation in 1916, though not complete in all details by that date. Since the original contracts have been completed some changes and improvements have been made and others are in contemplation for the near future.

The plant is located about 5 miles in a southerly direction from the center of the city. The outfall sewer is 3½ feet in diameter, partly concrete and partly segment block. At the entrance to the plant it becomes rectangular, 4 feet wide and 18 inches deep.

58-2


Screen Chamber
Grit Chamber
2
4
6
8
10
12
14
16
Contact
Beds
1
3
5
7
9
11
13
15
Sludge Lagoon
NIMISHILLEN
CREEK
Scale

[illegible] (Face p. [illegible])

Fig. 2.—General plan of the sewage-treatment plant at Canton, Ohio.

The sewage enters a small chamber from which it is diverted into one of two channels containing coarse screens with ¾ to 1 inch clear openings. At the outlet of the screen chamber there is a recording device to measure the flow over the weirs.

These weirs discharge into two grit chambers, a weir for each chamber. They are equipped with adjustable or false bottoms or baffles running longitudinally.

The screen and grit chambers are inclosed in a substantial brick building vented by a high stack to reduce odors. Provision has also been made in this building for the installation of an incinerator to burn screenings.

The grit chambers outlet into a long flume which carries the sewage to the Imhoff tanks. There are six of these tanks arranged in two sets of three each. In each set, the three tanks can be operated in parallel or series. If operated in parallel, the direction of flow can not be reversed, but when in series, while the direction of flow in the separate tanks can not be reversed, the order of the two outside tanks can be changed, so that either one can stand as first or third in the series. Under normal operation the tanks are connected in series. The individual tanks are rectangular in shape and of the double flow chamber type with a central gas vent running the entire length of the tank.

The final treatment device following the Imhoff tanks consists of contact beds. These are arranged in 16 units of one-half acre, making 8 acres in all. The material in the beds is crushed slag, with gravel around the distributing duct. The beds to be used are selected by the operator, the inlet to each bed being controlled by a hand-operated valve. An alarm bell gives notice of the filling of a bed, and the inlet is then closed by hand. The contact and discharge periods are automatically controlled by siphons. The effluent is discharged to a main collecting gallery and thence in a rectangular sewer into Nimishillen Creek.

For sludge treatment there were, at the time of inspection, six specially prepared sludge beds, each 150 feet long by 24 feet wide, and provided with narrow gauge tracks for loading cars with dried sludge.

The filtering material consists of 15 inches of sand laid over gravel, the depth of the gravel varying from zero at the sides to 6 inches at the middle, down which a 6-inch drain is laid in a trough. This drain discharges directly into the creek. As originally constructed no special bottom was laid. After a period of operation, however, several beds have been modified by the installation of concrete bottoms.

Three of the six beds have glass covers of standard greenhouse construction. The purpose is to give 12 months use of the beds and to protect drying sludge from rain.

The six beds, described above, have not been adequate to handle all sludge produced. A sludge well has, therefore, been installed from which sludge is pumped to low-lying areas or onto fields. In addition, at the time of the inspection more sludge beds were being prepared. No special bottom or filtering material was to be used, as the soil is a natural gravel and, it is felt, will drain readily. The construction, therefore, is to consist in removing the top soil and leveling the chosen area. These beds are 54 feet wide and of a total length of about 700 feet, divided into five beds 125 to 150 feet long.

Laboratory facilities are provided at the plant, one room of a general administration building being devoted to this use. The equipment, however, is only fair and inadequate for the properly carrying out of this phase of the work.

The city engineer has general supervision over the plant, the direct operation being under a superintendent directed by the city engineer. The superintendent is interested in the plant, and is giving excellent supervision. The city engineer gives the treatment plant much more personal attention than is generally customary where there is a superintendent on duty at the plant. In addition to the superintendent there are four regular laborers, and others as needed. The laboratory is under a part-time chemist, who spends three days a week at the plant.[b]

In general appearance, the plant might be termed a "show" plant. The grounds are well taken care of, attractively planted and kept clean.

The results of the chemical analyses made at this plant are contained in the following table.

TABLE No. 27.—*Results of chemical analyses at the Canton (Ohio) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.				Settleable solids, 2 hours c. c. per liter.[a]			Oxygen consumed 30′ in boiling water.			Alkalinity as CaCO₃ by M. O.			Ether soluble matter 24-hour comp. raw.	Chlorine as chlorides.		
	Raw.	Effluent Imhoff tanks.	Effluent contact beds.	Raw supernatant.	Raw.	Effluent Imhoff tanks.	Effluent contact beds.	Raw.	Effluent Imhoff tanks.	Effluent contact beds.	Raw.	Effluent Imhoff tanks.	Effluent contact beds.		Raw.	Effluent Imhoff tanks.	Effluent contact beds.
June 23	216	96	46	54	5.5	1.0	.....	67	41	23	320	330	332	52	68	69	69
24	244	88	46	56	5.5	0.2	Tr.	69	41	16	336	340	336	50	68	72	68
25	256	84	38	56	5.0	.1	Tr.	62	42	20	352	340	352	61	72	73	72
26	350	72	40	71	5.0	.1	.....	55	31	16	354	332	356	....	73	74	76
27	252	72	34	44	5.0	.2	Tr.	61	38	16	348	348	348	59	96	88	84
28	208	84	32	64	4.5	.1	Tr.	61	27	11	340	360	370	45	82	84	82
29	280	120	46	92	4.5	.2	Tr.	63	53	20	348	360	372	90	75	76	74
30	256	96	44	58	4.5	.3	Tr.	62	34	16	336	340	352	64	90	82	86
July 1	288	108	44	90	5.0	.5	Tr.	57	34	16	336	372	352	65	90	83	82
2	260	108	32	46	8.5	.5	Tr.	60	37	18	348	340	380	66	74	76	78
Average	261	93	41	63	5.3	.3	Tr.	61	38	18	342	343	354	62	79	75	76

[a] Tr. indicates less than 0.1 c. c.

[b] Since the survey a full-time chemist has been employed.

TABLE NO. 27.—*Results of chemical analyses at the Canton (Ohio) sewage-treatment plant*—Continued.

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.						Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.						Nitrogen as nitrates, effluent contact beds.
	Raw.		Effluent Imhoff tank.		Effluent contact beds.		Raw.	Effluent contact beds.	Raw.		Effluent Imhoff tank.		Effluent contact beds.		
									Per cent concentration.						
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.			5	10	5	10	20	40	
June 23	92	176	72	120	16	42	......	0.3	....	....	......	....	......	....	0.1
24	112	168	98	132	16	37	......	.2	....	52	......	42	216+	72	.5
25	112	248	80	196	23	51	0.0	.5	72	24	[illegible]	50	96	....	.3
26	120	200	65	100	19	32	.4	......	48	26	[illegible]	26	144+	48	.2
27	110	195	85	110	16	28	.0	.5	72	44	120+	44	120+	44	.2
28	135	185	80	125	14	33	2.2	1.8	82	24	120+	24	96	48	.4
29	130	260	95	145	23	43	.0	......	....	....	......	....	......	....	.3
30	105	245	65	115	18	41	.0	.8	54	22	120+	48	120+	48	.3
July 1	130	280	90	155	17	41	.0	.0	96	24	120+	30	120+	24	.3
2	135	190	70	90	12	22	1.2	1.2	....	....	......	....	......	....	.3
Average	118	213	80	129	17	37	.5	.7	....	....	......	....	......	....	.3

The raw sewage is one of the strongest studied during the survey. A comparative discussion of the sewage analyses obtained at the different plants is to be found in another section of this report, but it can be stated here that the suspended solids content was equaled or exceeded at only two plants, the oxygen consumed at three plants, while the oxygen demand was not equaled anywhere.

The tanks removed 63 per cent of the suspended solids, effected a 38 per cent reduction in the oxygen consumed, and 42 per cent reduction in the oxygen demand, but notwithstanding this the tank effluent was stronger than was the raw sewage at several other places.

In spite of the strength of the tank effluent, the contact bed effluent contained less suspended solids than the average trickling filter studied. Though the per cent removal of the solids was not as great as that accomplished by the contact beds at Alliance, Ohio, the other contact installation studied, the actual amount of solids retained in the beds was exactly the same for both places; that is, 52 parts per million. The oxygen demand was rather high, and the nitrification, as evidenced by the nitrates, was low.

Nimishillen Creek, the receiving body of water, has an estimated minimum flow of 20 second-feet. Any normal stream of this size could easily take the load of the plant effluent without creating any nuisance or being rendered unsuitable for any except water-supply purposes. But Nimishillen Creek is badly polluted with industrial wastes and some sewage before reaching the treatment plant, so that physically the appearance of the plant effluent was better than that of the water in the creek.

The available cost data are mostly on the basis of unit prices, so that it is almost impossible to separate the totals among the various devices. Thus, though the actual construction of the Imhoff tanks is a lump-sum bid, the excavation is not included, and the excavation item includes also that for the contact beds. The total construction cost of the original plant was $272,472, to which must be added the cost of the land, $25,107, which includes a farm at $13,782, purchased to avoid a damage suit, together with the cost of buildings and other permamnent improvements, amounting to $18,621. This gives a complete total of $316,200 for the treatment plant alone, not including the outfall sewer from the city to the plant. On a designed capacity of 6 m. g. d., the above figure is equivalent to $52,700 per m. g. d. capacity.

The operation and maintenance costs for the year 1919 were $10,948, divided as follows:

Supervision and labor	$8,947
Tools, supplies, incidentals	1,531
Horses and wagons	470

It should be noted, however, that these figures include some work done on the city's farm at which the plant is located, the item of horses and wagons being almost entirely chargeable to this. On the other hand interest, depreciation, and clerical services are not charged to the plant. Accepting the total as actually charged against the plant, the cost per million gallons treated was about $6.75.

V. Columbus, Ohio.

The engineering survey of the sewage treatment plant at Columbus, Ohio, was made July 28 to August 2, 1920. The laboratory studies followed about two months later, October 1 to 12.

Columbus is a progressive city of 237,000 population located in the central part of Ohio on the Scioto and Olentangy Rivers. It is the State capital, seat of the State university, and an important railroad and industrial center, the industries including starch works, dye manufacturers, tanning, iron and steel mills and fabricators, breweries, creameries, and wool-scouring plants.

The sewers of Columbus are partly of the combined and partly of the separate type. The main sewerage district, comprising about 80 per cent of the area of the city, takes in the territory east of and adjacent to the Olentangy and Scioto Rivers. This district is sewered on the combined plan. The collecting sewers discharge into an interceptor, provided with overflows by which most of the storm flow is by-passed direct to the rivers. It discharges into the main sewage pumping station.

The east-side sewer district, lying adjacent to Alum Creek, is also on the combined plan. The sewage from this section is carried to the

62a

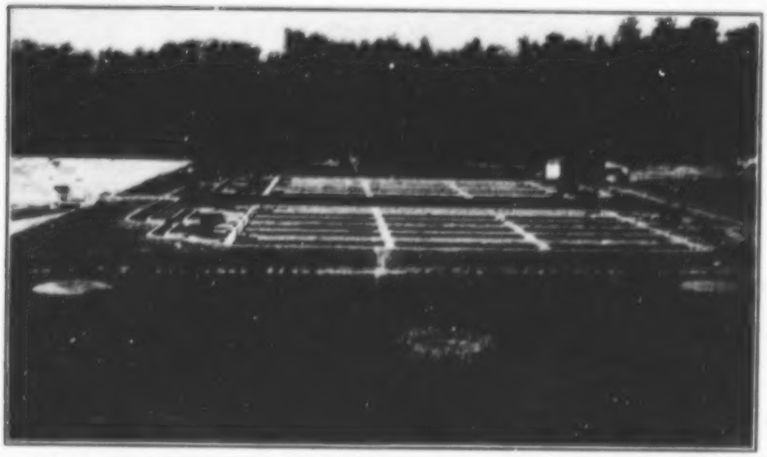


FIG. 8.—IMHOFF TANKS AND CORNER OF CONTACT BEDS AT CANTON, OHIO.

east side pumping station, which lifts it into the sewer system of the main sewerage district. Arrangements are made in this district for the overflow of excess storm flow or the by-passing of the entire flow into Alum Creek during high water in the creek. The force main from the pumping station to the interceptor is 20 inches in diameter and 8,180 feet long.

The west-side sewerage district includes that part of the city west of the Scioto River. This district is sewered on the separate plan. Both the storm and sanitary sewers drain to the main sewage pumping station. The storm sewer, however, discharges directly into the river except when the river is high, when it is pumped to the river. The sanitary sewage, together with that from the main interceptor including the east-side flow, is pumped to the sewage treatment plant during the warm months, which is the only time the sewage is treated. During the winter months all sewers discharge direct to the river, except, as noted above, that from the west side, which has to be pumped to the river when the river is higher than the outlet of the west-side sewers.

Infiltration is considered to be about average, except during excessive rainfall, when this factor runs high.

The grades on the west-side sewers are for the most part fairly flat, the laterals running 0.3 per cent and the trunk sewer about 0.05. Conditions are better on the east side. Here the average grades are 0.4 to 0.6 with variation from 0.3 to 2 and 3 per cent.

Cleaning and flushing is done mostly by hose and is practiced as a rule only when stoppages or odor nuisance occur. There are, however, some 150 to 200 flush tanks on the system, but these do not operate continuously or automatically.

The 1919 annual report shows a total of 397 miles of sewers. Since that time about 10 to 15 miles have been added, making a total for July, 1920, of about 410 miles. Detailed data covering the amount of various sizes were not available.

The 1920 census gives Columbus a population of 237,000. Of this it is estimated that 95 per cent, or about 225,000, are connected to the sewers. There is no accurate record of the connections to the sewers, but the waterworks department records show about 41,000 water connections as of January 1, 1921, and this probably is a fair estimate of the number of sewer connections.

The main sewage pumping station is located on the west side of and adjacent to the Scioto River. The east-side intercepting sewer, the west-side sanitary sewer, and the west-side storm sewer all discharge at this point. All the sewage to be treated is pumped from here to the treatment works. This includes all the sanitary sewage of the city and a part of the storm flow, the strictly storm sewage from the west side discharging directly into the river.

In addition to pumping sewage to the treatment works this station is also used, during high stages of the river, to pump all the drainage of the west side to the river. This is necessitated by the low elevation of the west-side sewers, the east-side interceptor being high enough to discharge into the river by gravity even at the high stages of the river.

The sewage entering this station is first passed through one of two sand catchers or grit chambers each 8 feet wide by 90 feet long, with a depth varying upon the position of the outlet gate. A derrick with grab bucket is provided for cleaning.

From the sand catcher the sewage passes through a 4-inch grid or coarse bar screen and then through two vertical bar-cage type screens in series, the first with 1-inch openings between ¾-inch bars, and the second with ½-inch clear openings between ⅜-inch bars. These are set under the floor of the pumping station and hoisted by an electric motor for cleaning.

The pumps and power equipment are as follows: Three De Laval centrifugal pumps of 5, 10, and 15 m. g. d. capacity, direct connected to 50, 100, and 150 horsepower, respectively, General Electric motors; one Morris centrifugal pump of 15 m. g. d. capacity, direct connected to a 150-horsepower General Electric motor; and one Worthington centrifugal pump with Weinman impeller, direct connected to a 75-horsepower General Electric motor. All pumps are single stage, double suction, closed impeller type, and all motors variable speed slip-ring type.

The static discharge head is 23½ feet, and the total for average pumping 28 feet. The flow is measured by a 48-inch integrating Venturi meter, which is read every two hours. The force main to the treatment plant is a 48-inch line 6,336 feet long. The main to the river is a 48-inch line 330 feet long.

The east side sewage pumping station is located at Main and Harlow Streets. This is provided with one grit chamber giving a 40-second detention at a 5-inch per second velocity. It is cleaned about twice a month by an orange-peel grab bucket without interruption of operation.

Following the grit chamber are two vertical bar, cage-type, hoist screens 4 feet 1⅜ inches high by 2 feet 10¾ inches wide, with the side screens flaring upstream to a width of 4 feet 6 inches. The bars are ¾-inch square with 1-inch clear openings. These screens are placed in series and operated simultaneously. When cleaning is necessary they are hoisted to the main floor from the pit by a small motor and raked by hand.

The pumping and power equipment consists of two 10-inch Weinman horizontal, single stage, double suction, open impeller centrifugal pumps, direct connected to 100 horsepower variable speed General Electric motors.

The static head is 52 feet, and the total 62 to 65 feet for average pumpage. The force main is a 20-inch line 8,180 feet long. The flow is measured through a 20-inch integrating Venturi meter which is read hourly.

The sewage received at the treatment plant is from both combined and separate sewers, that from the combined sewers predominating. All of it is pumped once and some of it twice. In appearance it is typical of the two types of sewage. During dry weather, when the flow is almost entirely sanitary, it has the common milky gray color with the normal suspended solids, paper, fecal matter, matches, corks, etc., and during storm periods the color is a dirty yellow.

Industrial wastes tributary to the sewers include those from iron pickling processes, starch works, tanneries, slaughterhouses, creameries, wool scouring, and brewing. Of these, only that from the starch works is visibly detectable at the treatment plant. This gives, at times, a milky white color to the sewage. It is not believed by those in charge of the plant that this waste or any of the others are of sufficient volume to materially affect the operation of any of the treatment devices.

In 1920, the average daily flow treated was 21.2 million gallons. This flow is applicable only to a period of 196 days from May to December, as the plant is not operated during the winter months.

For unsewered sections of the city, night soil disposal is provided free of charge, and, in addition, night soil for a section without the city limits is taken care of at the city station. For this latter service a charge of $2 per load is made for disposal. In 1919, a total of 380 loads were handled. This figure covers the entire year, and hence, not all of it was received at the treatment plant.

The original sewage treatment plant, designed by Mr. J. H. Gregory, engineer for Messrs. Hering & Fuller, was put in operation in 1908. Many minor changes have been made from time to time and one important alteration, that of converting the septic tanks into Imhoff tanks, was made in 1915 and 1916.

Sewage is discharged at the plant from the 48-inch force line from the main pumping station. As already described, preliminary devices, consisting of sand catchers and bar screens, are located at the pumping stations.

From the force main the sewage enters the distributing conduits which lead to the 22 Imhoff tanks. These are of three different sizes, due to structural requirements in rebuilding them out of the original septic tanks. The effluent from these tanks passes to a storage tank from which it is applied to the trickling filters by a hand-operated dosing mechanism. A float indicates the height of the sewage in the storage well. At a certain elevation in this well, the gates to the filters are opened by hand. Dosing is continued till the level has dropped to an established point, and the gates are then closed.

The trickling filters are in the shape of equilateral triangles laid on the plan of a hexagon with the control house at the center. Only four of the six triangular units have been constructed. Each covers an area of 2½ acres divided into two filters of 1¼ acres each. The distribution system is laid on the bottom with risers to the nozzles. The collecting system consists of half tile laid on sloping bottoms. The filtering material is 1 to 3 inch stone laid to an average depth of 5½ feet.

The effluent from the tricking filters is carried in a 66-inch circular conduit directly to the river.

There are in place, as part of the original plant, two secondary sedimentation tanks which were designed to receive the effluent from the trickling filters. These, however, are now regularly bypassed.

The sludge-drying beds are adjacent to the Imhoff tanks; their area, however, is only one-third to one-quarter large enough. The sludge is shoveled into cars run on tracks down the center of each bed. When filled the cars are hauled by a gasoline locomotive up the levee, where they are dumped on the slope.

Adequate laboratory and office facilities are provided on the second floor of the filter-control house. The supervision of the plant is under a competent chemist, with a regular personnel consisting of an attendant and eight laborers. The personnel is sufficient to operate the treatment plant but not to do much toward beautifying the grounds. The grounds, are, however, kept clean and orderly. This lack of attention to the grounds is due in a measure to the fact that the treatment plant is operated only seven or eight months in the year.

66-a

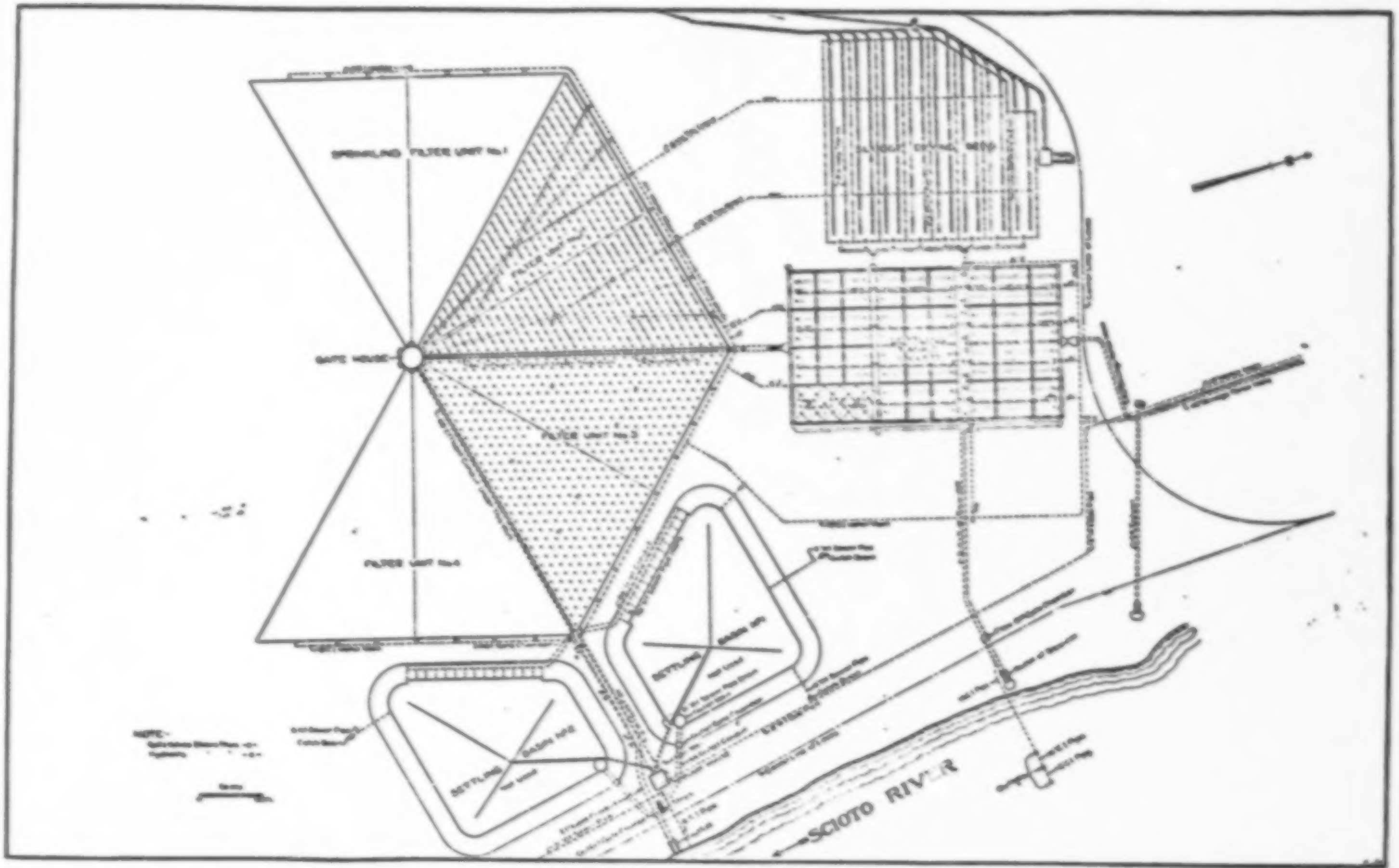

SPRINKLING FILTER UNIT No. 1
FILTER UNIT No. 2
FILTER UNIT No. 3
FILTER UNIT No. 4
GATE HOUSE
SETTLING BASIN No. 1
SETTLING BASIN No. 2
SCIOTO RIVER
NOTE:—

Fig. 8.—General plan of sewage treatment plant at Columbus, Ohio.

[illegible] (Face p. 66)

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 28.—*Results of chemical analyses at the Columbus (Ohio) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.				Settleable solids, 2 hours, c. c. per liter.[1]			Oxygen consumed 30' in boiling water.			Alkalinity as CaCO₃ by M. O.			[illegible]	Chlorine as chlorides.		
	Raw.	Effluent Imhoff tanks.	Effluent trickling filters.	Raw supernatant.	Raw.	Effluent Imhoff tanks.	Effluent trickling filters.	Raw.	Effluent Imhoff tanks.	Effluent trickling filters.	Raw.	Effluent Imhoff tanks.	Effluent trickling filters.		Raw.	Effluent Imhoff tanks.	Effluent trickling filters.
Oct. 2	144	64	36	42	3.3	Tr.	0.4	55	34	22	216	216	166	200	115	115	116
3	172	88	72	88	2.6	0.9	.6	48	39	25	206	200	172	107	100	115	126
4	146	88	60	74	1.8	Tr.	.9	51	35	26	216	222	200	87	100	90	106
5	260	94	112	64	5.0	.4	1.6	60	38	24	204	220	196	100	100	106	106
6	200	66	96	72	3.0	Tr.	1.2	64	32	30	208	226	194	[illegible]	110	115	110
7	238	79	85	80	3.0	.4	1.0	60	48	25	214	216	194	90	106	106	110
8	208	74	65	46	2.2	Tr.	1.0	75	53	34	212	220	197	30	142	122	146
9	230	93	136	73	3.0	Tr.	1.7	71	44	34	208	220	[illegible]	54	110	112	126
10	224	51	88	73	3.7	Tr.	1.3	62	46	21	212	212	200	70	115	110	110
11	144	86	86	41	2.0	Tr.	.8	48	37	26	206	216	190	60	110	106	110
12	230	55	96	73	4.4	.2	.8	77	60	29	214	226	[illegible]	......	100	100	106
Average	206	79	81	60	3.1	Tr.	1.0	63	46	26	211	219	190	100	113	112	115

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.						Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.			Nitrogen as nitrates. Effluent trickling filters.
	Raw.		Effluent Imhoff tanks.		Effluent trickling filters.		Raw.	Effluent trickling filters.	Raw.	Effluent Imhoff tanks.	Effluent trickling filters.	
									Per cent concentration.			
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.			10	10	100	
Oct. 2	80	192	60	136	13	35	0.0	3.6	40	80	97	0.6
3	52	164	48	132	13	44	1.0	4.7	46	70	70	.3
4	48	152	36	90	11	40	1.1	5.2	110	174	110	1.6
5	98	212	73	146	18	41	1.6	5.8	47	93	54	.4
6	92	208	72	148	20	55	1.7	4.8	29	97	71	.2
7	96	214	68	136	14	60	.5	4.0	67	73	73	.6
8	92	204	72	152	20	58	3.4	7.9	48	54	73	.6
9	64	184	36	120	26	64	.0	1.6	48	48	48	.5
10	116	196	60	152	30	56	2.1	3.4	71	96	71	.4
11	......	......	......	......	......	......	2.0	5.0	71	95	95	.5
12	......	......	......	......	......	......	2.6	5.6	24	48	73	1.0
Average	80	190	61	134	17	49	1.7	4.5	......	......	......	.6

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[1] Tr. indicates less than 0.1 c. c.

The strength of the raw sewage is well above the average of those found at other plants during the summer. The suspended solids are 10 per cent lower than those obtained by the chemist in charge of the plant during the same period, but they are within 4 per cent of the average of all results obtained at the Columbus testing station in 1905. In some other respects the strength of the sewage seems to have increased since that date. The oxygen consumed value obtained on the survey is 69 as against 51, the average for the 1905 tests, and the chlorine value is 113 as against 65.

The presence of dissolved oxygen in all but two samples was unexpected. The sewage is considered to be normally septic and has the typical septic odor. Mr. George W. Fuller[7] states:

> As delivered through the force main to the sewage-purification works at Columbus, the sewage is understood to be uniformly lacking in dissolved oxygen, as noted from the operation on the main works.

The 5-day oxygen demand is the second highest found during the summer's work.

The suspended solids in the tank effluent obtained by the survey chemist are considerably lower than corresponding results of the local laboratory, but those for the filter effluent agree very closely, being 81 and 83, respectively, for the survey and the local chemist. The 5-day oxygen demand value is the maximum obtained during the summer for a secondary treatment device. These results are due to the condition of the filters, which were badly clogged during the entire season, pooling being evident over a considerable area of the beds.

Unfortunately the receiving body of water is not sufficiently large to care satisfactorily for an effluent of this character at all times. The dilution in the Scioto River is usually less than one and often less than one-fifth. In addition there is a gross pollution of the stream above the plant which tends to nullify the benefits of sewage treatment.

The construction costs at this city are more or less involved because of extensive improvements and changes that have been made. It is not possible to estimate the costs as the plant stands. The following table, therefore, contains the original costs and the modification costs. The original costs are tabulated in great detail in a paper by John H. Gregory, published in the Transactions of the American Society of Civil Engineers, volume 67, pages 308 to 312.

TABLE No. 29.—*Costs of construction of the Columbus (Ohio) sewage-treatment plant.*

Item.	Original costs, 1907-8.	Modification costs, 1909-1920.	Total.
Sewage treatment works	$396,050	$322,644	$718,694
Main sewage pumping station	272,570	39,667	312,237
East side sewage pumping station	73,399	5,916	79,315
Night soil station	1,741	391	2,132
Experimental investigations	46,280	....	46,280
Miscellaneous	346,460	6,620	353,080
Engineering	107,560	....	107,560
Total	1,362,761	306,486	1,661,247

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[7] "Sewage Disposal," by George W. Fuller, 1912 edition, p. 26.

The operating costs for the year 1919 are given in the following table:

TABLE No. 30.—*Summary of cost of operation of the Columbus (Ohio) sewage-treatment works for the year 1919.*

Item.	East side pumping station.	Main pumping station.	Sewage-treatment plant.	Total.
Labor:				
Monthly		$10,826.55	$4,473.00	$15,479.55
Daily	$5,120.00	1,024.83	3,933.14	6,987.97
Power	5,824.07	7,371.28		13,195.35
Supplies and equipment	666.88	1,726.24	594.87	2,987.99
Miscellaneous	107.60	155.66	125.02	388.28
Maintenance of filters			899.66	899.66
Interest				66,375.00
Sinking fund				30,765.00
Total	11,718.55	21,114.56	11,026.71	139,973.13

The average daily volume of sewage treated during 1919 was 16.8 m. g., and the treatment plant was operated 227 days. During this year, however, the total flow of sewage was not pumped to the treatment plant. The data for 1920 giving 21.2 m. g. d. treated is a much more correct figure for use in computing unit costs. Using this figure with the 1919 operating cost data, the cost of treatment alone was $2.48 per m. g. d., and the total cost of disposal including pumping, night-soil disposal, and interest and sinking fund was $28.86 per m. g.

VI. FITCHBURG, MASS.

The engineering survey of the sewage-treatment plant at Fitchburg, Mass., was made June 29 to July 3, 1920. The laboratory studies followed about six weeks later, September 15 to 25.

Fitchburg is an industrial city of 41,000 population (1920 census), located in the north-central part of Massachusetts on the north branch of the Nashua River. The principal industries are the manufacture of textiles and paper goods. In addition there are important foundries, plants for the production of iron and steel goods, and large railroad shops.

The sewerage system is a combination of the combined and separate systems. The sewers existent at the time when definite steps were first taken toward a treatment plant were of the combined type. Since 1911 all new construction has been made with the aim of making as complete a separation of sanitary from storm sewage as is possible. In addition some separation has been made in the sewers existent before 1911, but entire separation is still far from being accomplished. In an article on the Fitchburg sewage-treatment plant in the June 7, 1913, issue of the Engineering Record the following statement is made:

> Mr. Eddy and Mr. Hartwell find that there are reasonable grounds for questioning the desirability of making a complete separation of sewage from storm water.

No accurate data are available as to infiltration or leakage. It was claimed that this was not excessive. However, the following quotation from the Engineering Record of June 7, 1913, discussing the factors of design considered for the Fitchburg sewerage system and sewage-treatment plant would indicate an amount of leakage of considerable volume:

> Provision has been made for an ultimate maximum rate of leakage of 1,960 gallons per acre per day, which is equivalent to 74,000 gallons per day per mile of sewer. Assuming the tributary area to be completely sewered.

Local topography allows ample grades in almost all instances. These range on an average from 1 to 20 per cent with a minimum of 0.5 per cent. Flushing is done entirely by hose and only when inspection indicates it is needed.

As on most combined systems, overflows are provided at a number of places to take care of excessive storm flows. These overflows or regulators in Fitchburg are arranged to operate at three to four times the normal dry weather flow. In addition there is a by-pass just ahead of the main inverted siphon under the river near the treatment plant. It is possible thus to discharge the siphon directly into the river.

The total mileage of sewers of various types and sizes was not definitely known. From the Thirteenth Semiannual Report of the Sewage Disposal Commission, the following sewers are listed as in place December 1, 1916:

BRICK AND CONCRETE SEWERS.

Size.	Length.	Size.	Length.
	Feet.		*Feet.*
14 by 21 inches	1,580	36 by 54 inches	600
16 by 24 inches	295	24 inches	6,164
18 by 27 inches	3,775	27 inches	2,050
20 by 30 inches	4,205	36 inches	3,244
22 by 33 inches	710	45 inches	2,900
26 by 39 inches	4,710	48 inches	3,780
28 by 42 inches	1,555		
30 by 45 inches	490	Total (7.81 miles)	41,344
32 by 48 inches	4,150		

PIPE SEWER.

6 inches	275	18 inches	15,609
8 inches	41,544	20 inches	6,373
10 inches	65,040	24 inches	1,457
12 inches	81,836	30 inches	5,434
15 inches	25,000	12 by 18 inches	595
16 inches	3,000	15 by 18 inches	1,080

The total of the two types is 54.26 miles. Since that date (December 1, 1916) 3.12 miles have been constructed up to December 1, 1919, giving a total of 57.38 miles of sanitary and combined sewers, the greater part of which are combined.

There are no records of the number of connections to the sewers. Mr. David A. Hartwell, commissioner of public works, estimated that the total contributing population was 37,000 to 38,000.

In physical appearance and odor, the sewage is received at the treatment plant in a fresh condition. However, the analyses made on this survey showed that dissolved oxygen was present in only 4 out of 11 samples. It is normally a dark gray in color, except on Mondays, when it becomes a light gray. From time to time also, it is distinctly reddish. This color was attributed by Mr. Allen, chemist in charge, to paper-mill wastes. He stated that the color permeated all the sewage in the tanks and that a light reddish yellow scum was formed on the surface. The filters, however, effect a complete removal.

Paper-mill wastes are also evidenced at the pumping station where the South Fitchburg sewage is forced into the siphon to the plant. Here the screenings contained, in addition to solids normally present in sewage, slimy masses, which appeared to be paper stock. The red color was not noticeable on the days of inspection. The paper mill from which this waste is supposed to originate has installed a sedimentation tank as a treatment preliminary to discharge into the the sewers, but an inspection of this tank, taken in connection with the screenings as described above, indicated either by-passing or very indifferent operation of the tank.[a]

In addition to this paper mill, a worsted mill discharges the waste from the scouring of 15 to 20 tons of wool per week. This waste is allowed to settle before discharging into the sewers under an agreement covering the maximum allowable flow during any one hour. The total flow is thus distributed to insure adequate dilution at all times.

On the whole, it is doubtful whether the industrial wastes are of such character or of sufficient volume to seriously affect the operation of the treatment plant.

More real difficulty is experienced with grit from the combined sewers. An effort is made to remove this in grit chambers through which the combined sewage is passed before entering the siphon to the plant, but it is found that a considerable amount is carried through these chambers to the plant, where it deposits in the sludge compartment of the Imhoff tanks.

During the year December, 1918, to December, 1919, an average of 3.351 m. g. d. was treated. The variation from the average is quite large. It was stated that the flow at times, though rarely, dropped to a rate as low as 0.5 m. g. d. while during storms it rose to a rate of 10 m. g. d. These extremes represent those received at the treatment plant. The siphon to the plant is capable of handling 14 m. g. d., but the siphons dosing the filters begin to operate continuously at a 10 m. g. d. rate, and for this reason, when the rate reaches this figure, the blow-off on the siphon to the plant is opened and the excess by-passed to the river.

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[a] Since the survey David A. Hartwell, commissioner of public works, has reported that this paper-mill waste goes direct to the river.

As early as 1896, the city engineer, Mr. David A. Hartwell, recommended the construction of intercepting sewers and a treatment plant. It was not until 1910, however, that a special legislative act authorized the appointment of a commission to undertake these needed improvements. Mr. Hartwell, formerly city engineer and now commissioner of public works, was chief engineer and superintendent of this commission and Mr. Harrison P. Eddy, of Boston, consulting engineer. Early in 1915 the intercepting sewers were constructed and all devices of the treatment plant were in operation. Practically no material changes or modifications have been made subsequent to that date.

Because of local topography the sewage is taken to the plant through a 30-inch inverted siphon, about 1 mile long. Previous to entering this siphon the sewage from the main part of the city is passed through a grit chamber. This chamber, located about one-third mile ahead of the siphon, is divided into two compartments, so that one can be cleaned while the other is in operation.

At the entrance to the siphon there is a coarse bar screen with 1⅜-inch openings.

The sewage from South Fitchburg, from what is known as the low-level system, is pumped into the siphon about one-third of a mile ahead of the treatment plant. At the pumping station there is a small sump intended to act as a grit chamber and a bar screen with ¾-inch clear openings.

The siphon discharges at the treatment plant through a 30 by 15 inch recording Venturi meter. From this it enters five Imhoff tanks under the siphon head through sluice-gate-controlled orifices. These tanks have three sedimentation chambers of the reversible-flow type.

The tanks discharge into two siphon chambers containing Merritt siphons automatically controlled to produce alternating discharges. They discharge onto 2 acres of trickling filters through Worcester nozzles.

The filter effluent is subjected to final sedimentation through four vertical radial-flow Dortmund tanks, and thence discharged into the North Branch of the Nashua River.

Sludge is dried on 11 sludge beds located adjacent to the Imhoff tanks, but at an elevation of 3 feet above the water level in these tanks, so that it has to be pumped. This is done by an air lift. In addition to the regular sludge beds use is made of some low areas

72a

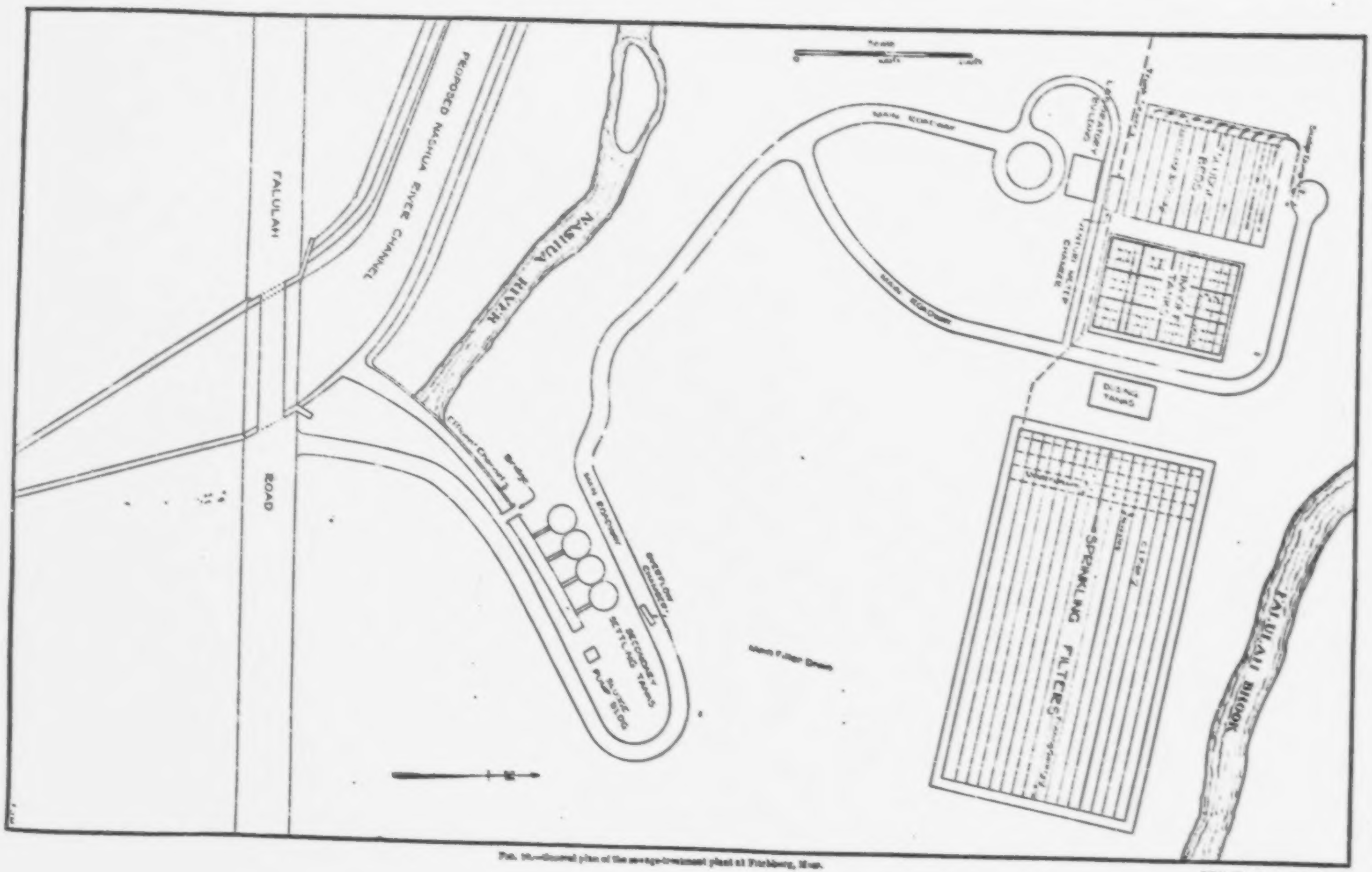
FALULAH BROOK
SPRINKLING FILTERS
DOSING TANKS
IMHOFF TANKS
SLUDGE BEDS
LABORATORY BUILDING
VENTURI METER CHAMBER
MAIN ROADWAY
MAIN ROADWAY
NASHUA RIVER
PROPOSED NASHUA RIVER CHANNEL
FALULAH
ROAD
OVERFLOW CHAMBER
SECONDARY SETTLING TANKS
SLUICE PUMP BLDG
Bridge
Effluent Channel
MAIN ROADWAY

FIG. 10.—General plan of the sewage-treatment plant at Fitchburg, Mass.

37169—22. (Face p. 78)

72b

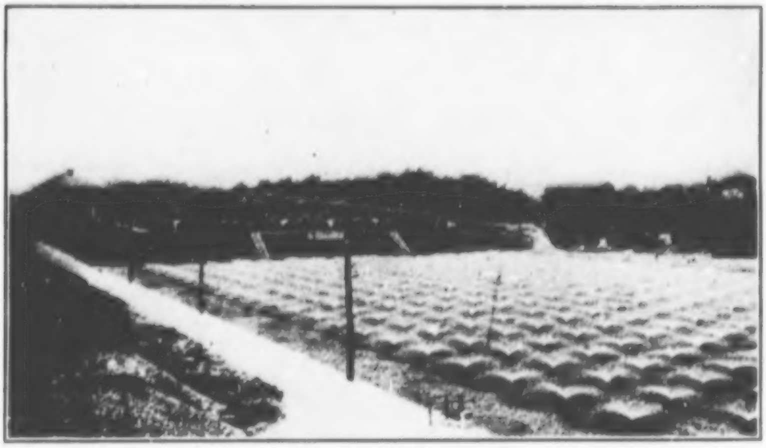

FIG. 11.—TRICKLING FILTERS, WITH IMHOFF TANKS IN THE BACKGROUND AT FITCHBURG, MASS.

adjacent to the plant. The sludge is finally disposed of by filling in low lands around the plant.

As stated before, the grit chambers can be by-passed. There is also a blow-off valve on the 30-inch inverted siphon to the plant where it crosses the north branch of the Nashua River, just before reaching the plant, thus making possible by-passing the entire plant. Within the plant itself by-passes are so arranged that any or all devices can be eliminated.

Laboratory facilities are very good. They are housed in an attractive administration building, which also contains the plant office, the air lifting machinery for the sludge, storerooms, and showers and toilet facilities for the men.

Operation is directed by the chemist in charge, who has under him a foreman and one laborer during the winter, but four laborers during the summer. In addition there are two watchmen.

The plant as a whole is unusually well kept up. The grounds are attractively parked and planted, and, what is of more importance, properly maintained.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 31.—*Results of chemical analyses at the Fitchburg (Mass.) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.					Settleable solids, 2 hours, c. c. per liter.[1]				Oxygen consumed 30' in boiling water.				Alkalinity as $CaCO_3$ by M. O.				Ether-soluble matter 24-hour comp. raw.	Chlorine as chlorides.			
	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw supernatant.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.		Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
Sept. 15	.....	.....	.....	.....	.....	2.5	Tr.	Tr.	Tr.	64	48	18	15	104	112	4	8	89	85	85	85	85
16	240	62	56	30	50	2.5	Tr.	Tr.	Tr.	61	36	20	14	100	108	12	8	56	70	70	70	70
17	300	64	52	40	58	2.5	Tr.	Tr.	Tr.	82	29	19	16	78	100	2	4	67	90	80	80	80
18	344	62	42	38	68	3.2	Tr.	Tr.	Tr.	73	40	20	16	100	94	2	4	54	75	70	70	70
19	280	64	42	54	58	2.5	Tr.	Tr.	Tr.	66	36	14	14	92	84	4	6	72	70	70	70	70
20	180	42	36	36	48	2.5	Tr.	Tr.	Tr.	60	33	15	13	104	104	2	2	50	60	60	65	65
21	336	62	44	38	62	3.0	Tr.	Tr.	Tr.	42	21	19	19	102	98	16	16	72	82	85	88	85
22	340	58	50	42	56	2.7	Tr.	Tr.	Tr.	74	46	24	22	96	102	17	21	64	50	55	55	60
23	324	70	60	46	50	3.0	Tr.	Tr.	Tr.	57	32	17	16	108	102	11	14	58	55	55	62	65
24	288	80	66	54	56	3.0	Tr.	Tr.	Tr.	64	36	20	17	104	100	12	13	62	65	65	65	65
25	340	68	72	46	50	3.0	Tr.	Tr.	Tr.	61	32	17	14	80	84	5	5	56	72	80	75	75
Average	207	63	52	42	56	2.7	Tr.	Tr.	Tr.	65	37	19	16	97	99	7.9	9.1	63	70	70	71	72

[1] Tr. indicates less than 0.01 c. c.

TABLE No. 33.—*Summary of cost of operation of the Fitchburg (Mass.) sewage-treatment plant for the fiscal year ending November 30, 1919.*

Account.	Total cost of operation and maintenance.	Cost per m. g. treated.	Cost per capita served.
Grit chambers	$1,340.80	$1.11	$0.037
Siphon chamber	263.82	.22	.006
Imhoff tanks	5,222.20	4.30	.139
Sludge beds	1,026.60	.85	.027
Trickling filters	1,[illegible].04	1.57	.046
Secondary tanks	1,843.61	1.52	.049
Total	11,506.07	9.56	.303

VII. HOUSTON, TEX.

The engineering survey of the sewage-treatment plants at Houston, Tex., was made August 16 to 20, 1920. The laboratory studies followed a little over two months later, October [illegible] to 26.

Houston is a city of a little over 147,000, located in the southwestern part of Texas. It is a distributing center for a large surrounding territory, and also contains a number of industrial plants relating principally to cotton, oil refining, agricultural pursuits, and shipping.

While there are two sewerage systems, each tributary to a separate treatment plant, separate discussions would involve much needless repetition. In this report, therefore, they are merged, and the points of difference mentioned in the general discussion.

The sewerage system is largely on the separate plan, there being only a small down-town business section, tributary to the northside treatment plant, served by combined sewers.

The city engineer does not feel that infiltration over the system as a whole is excessive, but considers it about average. However, he stated that some roof drains were illegally connected to the sanitary sewers, and he considers surface leakage through manhole covers the source of considerable storm water in the sewers. In addition, breaks at isolated points frequently admit large volumes of storm water carrying much mud and grit. It is clearly evident, from the sharp rise in flow and the character of the sewage received at the plants during periods of storm, that large volumes of surface and ground water do enter the sanitary sewers. This volume is at times so large and carries so much grit that it is necessary to by-pass the plants.

While much of the sewered territory is flat, every effort is made to attain grades sufficient to give velocities of 2 feet per second. Eight-inch lines, which is the prevailing size, have grades averaging 0.3 to 0.4 per cent. The larger sizes are laid on flatter grades, 36-inch lines having slopes of 0.045 per cent.

Flushing is done largely by a hose connected to a fire hydrant, though there are some flush tanks on the system. There is no regular flushing schedule, stoppages being taken care of as they occur.

The mileage of the different size sewers was not available, nor was it possible to divide the total mileage between the two plants. On January 1, 1920, the total mileage of the city was 170.

It was estimated that a total population of 100,000 or 68 per cent of the entire city was tributary to the sewers at the time of the survey. There are about 14,000 connections to the sewers, giving an average of seven people per connection. It was further estimated that 80 per cent of the contributing population was served by the north-side treatment plant and 20 per cent by the south-side plant.

There are 20 storm overflows on the system and it was estimated that 10 per cent of the flow is by-passed at these points.

On that part of the system tributary to the north-side plant there are three pumping stations. Two of these, one known as the Houston Heights station and the other as the Westmoreland station, located in the northeast and southwest sections of the city, respectively, pump to the main or Willow Street station. All three stations are provided with screens, but only one, the Willow Street station, has a grit chamber. After passing through the screens and grit chamber at this station, the sewage is lifted by centrifugal pumps to the concrete gravity line to the north-side treatment plant.

The bulk of the sewage received at the south side plant is pumped at the south side pumping station. Here it is passed through a screen with 1-inch clear openings and some of the heavy grit drops in a well provided for this purpose.

The character of the sewage received at both plants depends to a considerable extent upon weather conditions. During dry weather, it has the appearance of a typical domestic sewage, apparently fresh after a maximum travel in the sewers of about six hours. It will be noted, however, in the tables of analyses that dissolved oxygen is only occassionally present. During wet rainy weather the character of the sewage is more nearly that from combined sewers, carrying excessive amounts of mud and grit. At such times it is customary to by-pass the entire flow around the plants.

The only industrial waste of any consequence is oil from power plants and factories which occasionally reach the north side plant in sufficient quantity to cause considerable interference in the operation of the plant. It is customary to by-pass the entire flow at such times. In addition to this waste, the north side plant receives the night soil from 12,000 privies, averaging about 1,200 gallons a day.

The average dry weather flow received at the north side plant is about 6 m. g. d. with variations of from 3.5 to 9.2 m. g. d. These figures do not include heavy storm flows, the volume of which is not definitely known, but is estimated to run as high as a 20 m. g. d. rate. They are, however, fairly representative of the volume actually treated since the very high storm flows are by-passed.

The average dry weather flow for the south side plant is 1½ m. g. d. with variations from 0.9 to 2.3 m. g. d. The general statements in the preceding paragraph relative to storm flows are applicable to this plant also.

The treatment plants were built in 1916 and 1917, and put in operation in 1917. They were designed by Mr. E. E. Sands, city engineer at that time. Some modifications have been made since that date, notably the removal of the iron castings holding the filtros plates, and the cementing of these plates directly to the bottom of the tanks. This work was done in 1920.

Sewage is received at the north side plant in a concrete gravity main. Most of it has, however, been pumped into this gravity main and some has been pumped twice.

At the plant itself the sewage enters the aeration tanks of which there are four in place, but only three being used. These tanks are long and narrow, the length being about 15½ times the width. About one-seventh of the bottom consists of filtros plates. In these tanks the sewage is under constant aeration for its entire length, receiving 1.5 cubic feet of air per gallon of sewage.

From the aeration tank the sewage flows to the sedimentation tanks through a long narrow channel in which aerators are placed at intervals to prevent sedimentation. It enters these tanks through flap gates located near the bottom of the inlet channel. These gates are opened to stand at an angle of 45° and act as downward deflectors. The effluent from these tanks passes to an outlet channel, and thence over a weir to the ship channel or bayou without further treatment.

Sludge settling in the final tanks is raised by air lifts to a reaeration tank of the same design as the sewage aeration tanks, except that it is only about one-half as wide. In this tank the sludge is aerated and carried back to the inlet of the sewage aeration tanks where it is mixed with the incoming sewage entering these tanks.

The flow of sewage through the plant is measured as it passes the final outlet weir by a recording gauge. The amount of air is measured by a Pitot tube inserted in a reduced section of 12-inch pipe. All air is screened to reduce clogging of the filtros plates.

Plants of this type require considerably more machinery than any other type of sewage treatment. At Houston the motors, air compressors, pumps, etc., are housed in a substantial attractive brick building.

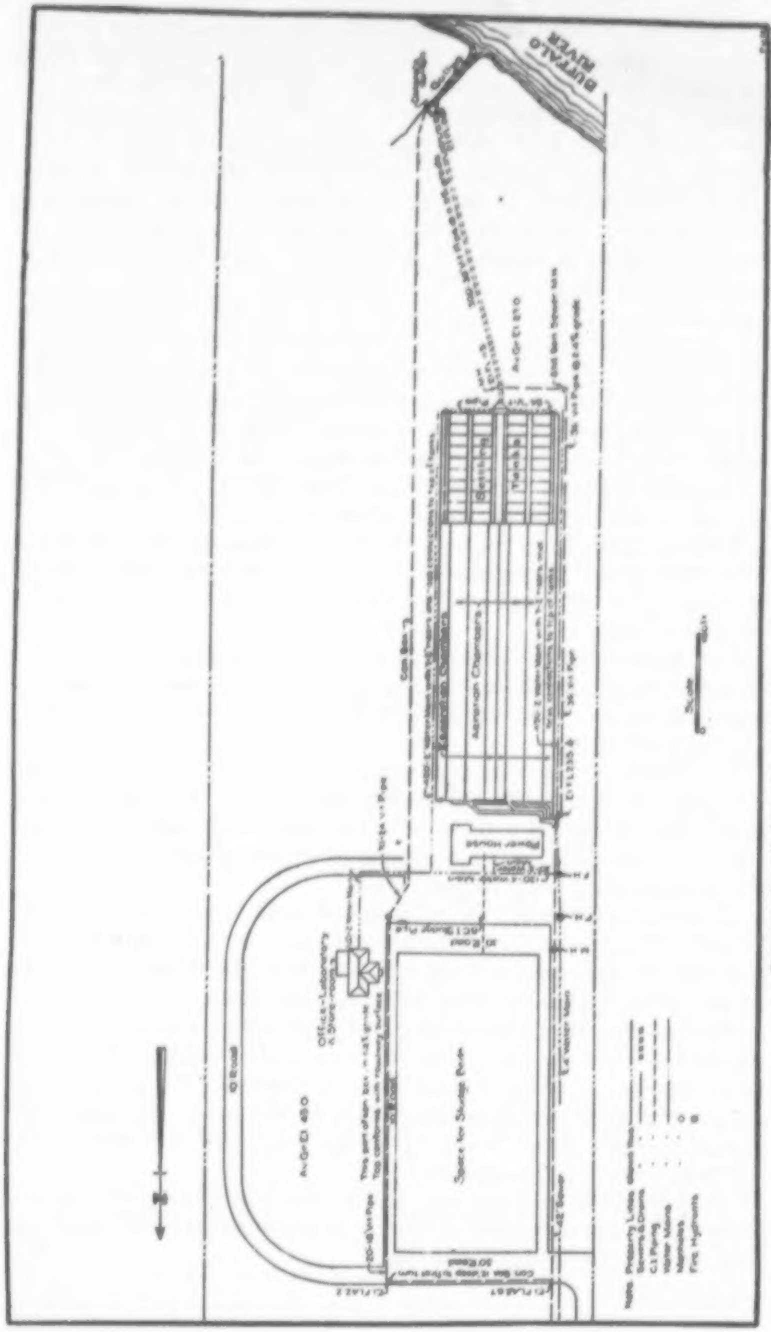
BUFFALO RIVER
Settling Tanks
Aeration Chambers
Power House
Office—Laboratory & Store-room
Space for Sludge Beds
Scale

FIG. 12.—General plan of the north-side sewage-treatment plant at Houston, Tex.

There are no overflows at the plant, but the entire flow can be by-passed around the plant, and this is done at times of storms when the flow is above the maximum capacity of the plant and when the sewage carries an excessive amount of grit which would settle out in the aeration tank and interfere with operation, or when, as occasionally happens, the sewage is carrying a large amount of oil wastes.

A dewatering plant to dry sludge has been installed, though not yet in operation. as it has been impossible to secure a proper conveyor. The sludge is to be pumped from the final tanks of the treatment plant to three large elevated wooden tanks where a short period of sedimentation is allowed. From these it flows by gravity to two ejectors, which force it into two large presses. The cake is dumped into storage bins to be picked up by the conveyor to a rotary dryer. After drying, the large lumps are screened out, ground, and rescreened, all screenings being carried to a storage room by a conveyor. It will be loaded from here into cars or wagons by a loading conveyor. At the time of the survey, sludge was being run to two large artificial lagoons, which had been used for about three years.

Laboratory facilities for both treatment plants are provided at the north-side plant. These consist of an adequately equipped laboratory in charge of a part-time student chemist, who is to be replaced by a full-time man.

The operation of the plant is in the hands of a chief operator, who operates the plant 8 hours and has general supervision over the two operators at the plant the remaining 16 hours. In addition there are three laborers.

Practically no improvements have been made in the grounds surrounding the plant. The treatment devices are concentrated in a small area, located in a basin with the land rising sharply on three sides. It was intimated that some steps toward planting and parking the grounds were being contemplated.

The south side treatment plant is the same in general design and in most of its details as the north-side plant, already described, except that it is just one-half as large. The air used is slightly more than at the north-side plant, being 1.7 as against 1.5 cubic feet per gallon.

There is no sludge-dewatering plant provided, and all sludge is pumped to a large lagoon. The future method to be adopted, whether more lagoons or some other means of disposal, is still unsettled. Experience with the dewatering plant at the north side plant and future possible development in sludge treatment will decide this question when the time comes.

The laboratory facilities provided at the north-side plant are sufficient to handle both plants, and only an office and tool house has been built at the south-side plant.

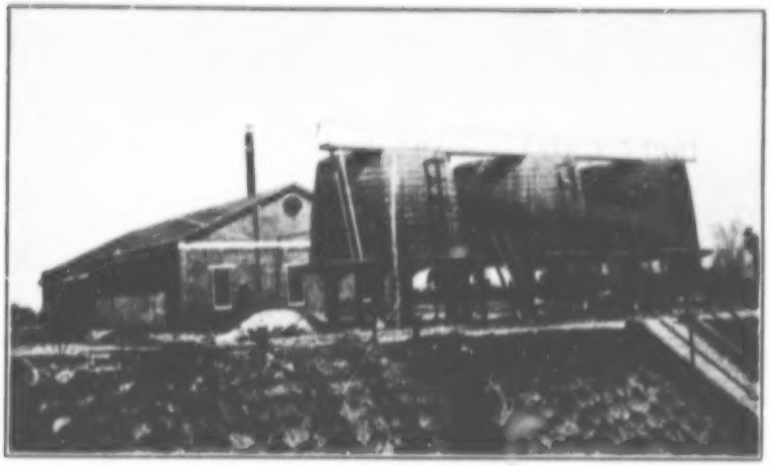

FIG. 13.—SLUDGE DRYING PLANT AT THE NORTH SIDE PLANT AT HOUSTON, TEX.

Operation is in the hands of a chief operator with two assistant operators and one laborer.

At the time of inspection very little attention had been given to improving the grounds around the plant.

The results of the chemical analyses made at the north-side plant are contained in the following table:

Table No. 34.—*Results of chemical analyses at the Houston, north-side sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.			Settleable solids, 2 hours c. c. per liter raw.	Oxygen consumed 30' in boiling water.		Alkalinity as $CaCO_3$ by M. O.		Ether soluble matter 24-hour comp. raw.	Chlorine as chlorides.	
	Raw.	Effluent final sedimentation tank.	Raw supernatant.		Raw.	Effluent final sedimentation tank.	Raw.	Effluent final sedimentation tank.		Raw.	Effluent final sedimentation tank.
Oct. 13	160	14	28	2.0	60	12.0	328	212	38	150	150
14	210	10	46	3.0	50	11.0	272	208	54	165	160
15	284	12	60	4.5	54	11.0	292	204	48	160	160
17	168	5	46	2.0	49	9.4	288	220	37	135	130
18	146	11	42	1.7	30	8.2	288	204	34	125	125
19	206	12	40	2.5	45	11.0	276	212	26	170	145
20	184	17	56	2.5	45	9.6	308	254	44	152	157
21	180	5	38	3.5	48	8.4	300	272	47	150	130
22	346	30	72	2.5	45	9.8	200	248	29	110	140
23	124	17	38	.7	20	11.0	168	128	17	75	110
25	......	60	......	......	......	10.0	......	104	......	......	85
26	194	6	44	3.0	45	10.0	248	128	42	100	100
Average	200	17	46	2.5	45	10.0	270	198	39	136	134

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C				Dissolved oxygen.		Hours to reduce M.B. at 20° ± C.		Nitrogen as—		
	Raw.		Effluent final sedimentation tank.		Raw.	Effluent final sedimentation tank.	Raw.	Effluent final sedimentation tank.	Ammonia.		Nitrates effluent final sedimentation tank.
							Per cent concentration.		Raw.	Effluent final sedimentation tank.	
	1-day.	5-day.	1-day.	5-day.			50	100			
Oct. 13	56	104	3.4	10.0	0.0	5.7	48	240+	9	2.0	8.8
14	84	160	2.1	6.4	.0	5.4	24	240+	16	2.2	4.8
15	56	140	2.4	5.5	.0	5.8	48	240+	27	2.7	5.2
17	44	100	3.5	12.0	.0	5.3	48	240+	18	10.0	4.8
18	36	84	3.3	7.5	.0	5.2	48	240+	20	5.0	1.2
19	40	98	4.2	24.0	.0	5.0	48	216+	15	4.8	1.0
20	90	160	3.6	13.0	.0	4.3	......	192+	27	7.2	1.4
21	56	128	2.5	12.0	.0	4.6	48	168+	......	......	2.4
22	28	68	5.0	10.0	.0	4.4	......	144+	10	8.0	2.4
23	32	......	......	......	1.7	5.3	......	120+	8	.7	9.6
25	......	......	......	......	......	6.2	......	72+	......	.5	9.6
Average	52	115	3.3	11	.2	5.2	......	......	17	4.3	4.6

With the exception of Baltimore, no raw sewage studied more closely approximated the average obtained from all plants surveyed. The suspended solids are about 15 per cent. high, but the other critical constituents, such as settleable solids, oxygen consumed and oxygen demand are unusually close to the average. The dissolved oxygen is rather less than was to be expected from the physical appearance of the sewage and its short travel in the sewers. Only at activated sludge plants was the ammonia-nitrogen determination made. At these plants it is of particular value as indicating the efficiency of the aeration, as measured by the reduction of this constituent.

This plant represents the largest permanent installation of the activated sludge process in this country. Judged by the effluent obtained at this plant, the process is undoubtedly capable of producing a thoroughly satisfactory effluent under actual operating conditions. It compares very favorably with the effluents from trickling filters studied on the survey. The suspended solids are lower than any trickling filter effluent, the reduction in oxygen consumed greater, the 5-day oxygen demand about the same as the properly operating filters, and the nitrates and nitrites well above the average. The effluent from this plant should be readily handled by any body of water capable of receiving the effluent from any type of plant of this capacity.

The results of the chemical analyses made at the south-side plant are contained in the following table:

TABLE NO. 35.—*Results of chemical analyses at the Houston south-side sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 9 a. m.—	Suspended matter.			Settleable solids, 2 hours c. c. per liter.[1]		Oxygen consumed 30′ in boiling water.		Alkalinity as CaCO₃ by M. O.		Ether soluble matter 24-hour comp., raw.	Chlorine as chlorides.	
	Raw.	Effluent final sedimentation tank.	Raw supernatant.	Raw.	Effluent final sedimentation tank.	Raw.	Effluent final sedimentation tank.	Raw.	Effluent final sedimentation tank.		Raw.	Effluent final sedimentation tank.
Oct. 12	......	5	......	Tr.	Tr.	......	6.8	......	196	......	......	107
13	196	5	46	2.0	Tr.	37	4.8	206	208	48	110	110
14	190	7	32	4.0	Tr.	45	6.4	202	220	34	120	120
15	372	6	36	2.5	Tr.	32	6.4	216	270	42	106	105
18	132	14	42	1.0	Tr.	30	7.6	200	208	21	109	107
19	194	3	20	1.5	Tr.	34	6.8	206	216	32	106	105
20	164	12	42	2.1	Tr.	37	6.0	208	220	34	110	110
21	92	1	48	2.5	Tr.	35	6.2	216	240	42	102	107
22	470	6	100	2.0	Tr.	41	6.2	208	224	31	60	100
23	......	14	......	......	......	......	6.8	......	204	......	......	90
Average	220	7.3	46	2.1	Tr.	36	6.4	204	220	36	101	106

[1] Tr. indicates less than 0.1 c. c.

TABLE No. 35.—*Results of chemical analyses at the Houston south-side sewage-treatment plant*—Continued.

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.				Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.		Nitrogen as—		
	Raw.		Effluent final sedimentation tank.		Raw.	Effluent final sedimentation tank.	Raw.	Effluent final sedimentation tank.	Ammonia.		Nitrates, effluent final sedimentation tank.
							Per cent concentration.		Raw.	Effluent final sedimentation tank.	
	1-day.	5-day.	1-day.	5-day.			10	100			
Oct. 12	......	......	2.0	6.0	0.0	7.5	......	240+	......	1.2	8.8
13	52	120	2.3	6.5	.0	7.3	48	240+	22	1.5	9.2
14	60	120	2.4	7.4	.0	7.8	72	240+	19	1.2	7.2
15	48	170	1.8	7.5	.0	8.3	24	240+	15	1.0	6.8
18	12	98	3.0	9.0	2.8	7.8	96	240+	20	2.0	.0
19	20	64	2.2	7.5	1.6	7.3	72	216+	18	1.0	4.2
20	40	112	2.5	8.0	.0	6.9	48	192+	24	3.0	7.2
21	48	104	2.3	7.5	.0	7.4	48	168+	......	......	4.0
22	20	......	2.5	7.0	2.4	6.9	......	144+	10	3.6	4.0
23	......	......	......	......	......	7.1	......	72+	......	.6	8.4
Average	36	112	2.3	7.4	.8	7.4	......	......	18	1.7	6.0

The raw sewage at this plant contained a higher suspended solid content than that at the north-side plant, but in other respects it was weaker, though not enough so to affect a comparison of the efficiency of the two plants. In such a comparison the effluent from the south-side plant shows up better than that from the north-side plant. It should be noted, however, that 1.7 cubic feet of air was used at this plant per gallon of sewage, while at the north-side plant the amount was 1.5. Moreover, it is not believed that the conditions at the north-side plant were normal during the period covered by the analyses. Just previous to this period there had been some trouble in maintaining the sludge in proper condition, due, it was stated, to excessive amounts of oil in the sewage, and a new supply of sludge was being built up. The chemist making the studies felt that under normal conditions the north-side plant produces fully as good an effluent as the south-side plant.

Taken by itself the effluent from the south-side plant is among the best found during the survey, containing within itself more dissolved oxygen than is required to satisfy the 5-day demand. The efficiency of aeration, as measured by the reduction of ammonia nitrogen, is particularly noteworthy, this constituent being reduced over 90 per cent, from 18 to 1.7 parts per million.

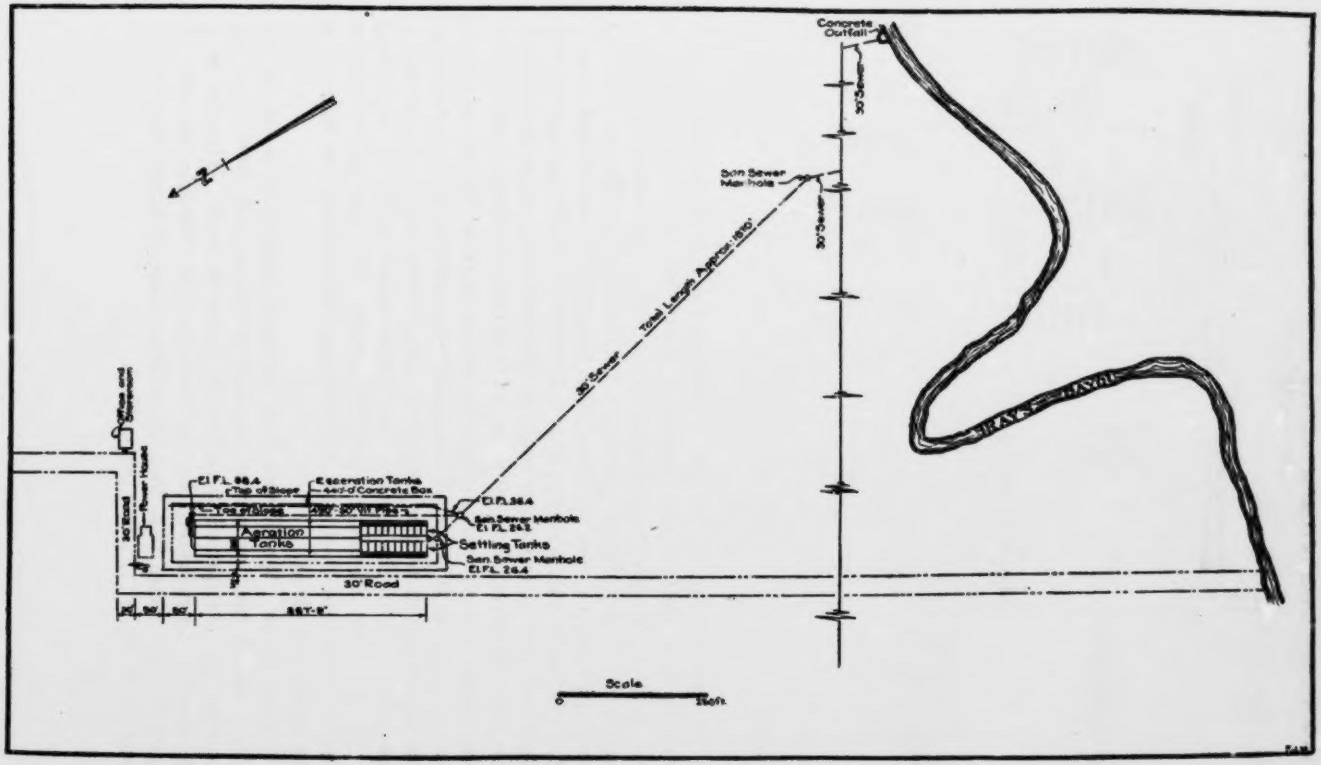
Concrete Outfall
30" Sewer
San. Sewer Manhole
30" Sewer
30" Sewer Total Length Approx. 1810'
Brays Bayou
El. Fl. 26.4
San. Sewer Manhole El. Fl. 24.2
Settling Tanks
San. Sewer Manhole El. Fl. 26.4
Aeration Tanks
Top of Slope
El. Fl. 26.4
Top of Slope
Office and Storeroom
Power House
30' Road
30' Road
Scale
0

Fig. 14.—General plan of the south-side sewage-treatment plant at Houston, Tex.

The construction costs of the two Houston plants are contained in the following table:

Table No. 36.—*Construction costs of the north-side and south-side sewage-treatment plants at Houston, Tex.*

Item.	North-side plant.	South-side plant.
Excavation	$25,822	$5,488
Tank buildings, etc	[1] 194,405	87,789
Air and power equipment	17,827	7,650
Filtros plates	6,439	2,800
Engineering	10,095	7,656
Miscellaneous	83	[2] 3,680
Resetting filtros plates—net	2,700	250
Total	257,371	115,313

[1] Does not include the $68,000 sludge drying plant.

[2] Includes water-supply system.

The operating cost for the year 1919 is contained in the following table. This table is arranged to give the cost per million gallons, treated on the basis of average treatment of 6 m. g. d. for the north-side plant and 1.5 m. g. d. for the south-side plant. It is noticed that depreciation and interest on the investment are not included.

Table No. 37.—*Operating costs per million gallons of the north-side and south-side sewage-treatment plants at Houston, Tex., for the year 1919.*

Item.	North-side plant.	South-side plant.
Power at 1 cent per kilowatt hour	$9.000	$8.000
Chief operator	.945	3.560
Two operators	1.445	5.780
Labor	1.875	2.667
Chemist, two-thirds for north, one-third for south	.600	.300
Supplies	.833	.890
Total	14.698	21.197

In considering these figures, allowance must be made for the fact that neither plant is operating at its capacity. Even allowing for this, however, the costs are well above the average for other types of plants of equal capacity.

VIII. Lexington, Ky.

The engineering survey of the sewage-treatment plant at Lexington, Ky., was made August 4 to 7, 1920. The laboratory studies followed immediately, August 11 to 21.

Lexington is a city of 41,500 population (1920 census), located in the central part of Kentucky. It is the center of a large, wealthy agricultural territory, and one of the important tobacco markets of the country. There are comparatively few industrial plants, none producing wastes of such character and volume as to affect the operation of a sewage-treatment plant.

The sewerage system is of the separate type. It was stated, however, that some roof drains are connected to the sanitary sewers, and that the storm sewers receive a small amount of strictly sanitary sewage. The exact extent of this deviation from the general policy of separation is not known.

Infiltration is well above the average, many of the sewers having been laid in water. Heavy storms always produce a marked increase in flow at the treatment plant, amounting to five to six times the dry-weather flow.

The grades are sufficient to insure a self-cleaning velocity of 2 feet per second when the sewers are flowing half full. Lateral sewers are laid on a 0.6 per cent average grade, the main or trunk sewers about 0.3 per cent and the 39-inch outfall to the plant on a 0.13 per cent.

Flushing or cleaning is done almost entirely by flush tanks, of which there are 140 on the system. Hose flushing is resorted to only in case of stoppages.

The following list of the various size pipes composing the sewerage system was obtained from the city engineer.

	Linear feet.		Linear feet.
5-inch (house connections)	75,000	18-inch	4,000
8-inch	185,000	20-inch	4,000
10-inch	6,000	24-inch	11,000
12-inch	3,000	39-inch	5,300
15-inch	18,000		

With the exception of the 39-inch, which is segmental block, all of the above are vitrified tile. The total mileage represented in the table is approximately 40.

It was estimated that there were 4,500 house connections to the sanitary sewers, through which sewage is received from 28,000 people. This figures 6.2 persons per connection.

There are two overflows on the sanitary system. These, it was stated, operate about five times a year, so that but very little sanitary sewage fails to reach the treatment plant because of these overflows.

The raw sewage received at the treatment plant has the physical appearance of a normal fresh sanitary or domestic sewage. While it was devoid of oxygen on seven out of ten days on which analyses were made, the travel in the sewers is relatively short, and no indication of advanced septic action was visible.

Industrial wastes, it was stated, are seldom detectable, though occasionally a small amount of slaughterhouse waste is observed. From a treatment standpoint, the industrial waste entering the sewers may be neglected.

The average dry weather flow was estimated at 2.5 m. g. d. This figure may be considered fairly accurate as it was obtained by counting, for a definite period on several different days, the number of times the siphon tanks discharged to the filters. No regular flow records are, however, kept. From the average of 2.5 m. g. d. the variations in dry-weather flow run from 1.0 to 3.5 m. g. d. At times when prolonged heavy rains cause large increases in the infiltration factor, the flow may reach a 14 m. g. d. rate, but it is customary to by-pass around the plant all in excess of a 5 m. g. d. rate.

The average water consumption throughout the year is 4 m. g. d. This includes industrial users, some of which, such as railroads, do not contribute sewage in proportion to their water consumption. Deducting industrial consumption, the domestic per capita consumption is about 60 gallons per day.

The treatment plant was designed by the Soloman-Norcross Co., consulting engineers of Atlanta, Ga. It was built in 1918, and was, therefore, in operation three years at the time of this survey. There have been no material enlargements or modifications made since the plant was put in operation.

The treatment plant is located west of, and about 2½ miles from the center of the city, and about a mile from the west boundary line. The sewage enters the plant through a segmental tile block sewer. It passes through an inclined coarse bar screen just before entering the grit chambers of which there are three. Two of these are, as a matter of general routine, operated in parallel with the third lying in reserve. From the grit chambers the sewage passes through an inverted siphon under the Louisville & Nashville Railroad tracks to the inlet conduit of the Imhoff tanks.

These are four reversible-flow, double-channel, medium deep tanks. The effluent from them is applied through two automatic siphon dosing tanks onto four trickling filter units. The individual underdrains of the filters discharge direct into the secondary sedimentation tanks. These are two long narrow tanks, each located between and serving two filter units. The two outlet conduits from these tanks lead direct to Town Branch, the receiving stream.

There are two sludge beds, each divided into four units, with an area of 210 square feet each. About 50 per cent of the dried sludge is hauled away by farmers.

By-passes are so located that the whole plant or any single unit can be cut out. In addition there is an emergency overflow just ahead of the bar screens.

A laboratory and administration building, included in the original design, is available, but has never been equipped for laboratory work. Analyses, of which eight sets were made in 1919, are made by a part-time chemist who also makes periodical inspections of the plant.

The plant is operated by a superintendent who lives at the plant. There is a watchman on duty at night and, by arrangement with the county in which the plant is located, four chain-gang laborers are available as needed.

Up to the time of the survey (August, 1920), very little work had been done around the grounds. The plant is comparatively new, and work has been held up by the war. The land is very poor but is being built up by sludge from the plant. Plans are well formulated for parking and improving the grounds. When these have been car-

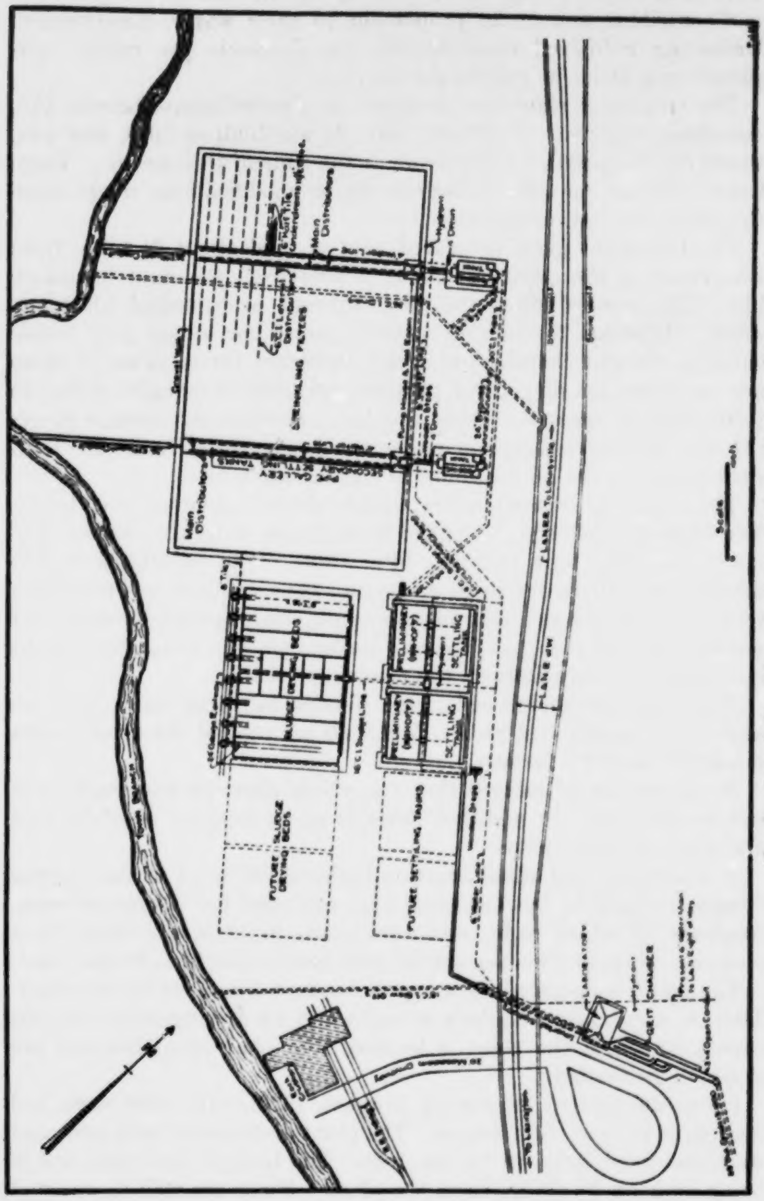
SPRINKLING FILTERS
SECONDARY SETTLING TANKS
PIPE GALLERY
Main Distributors
SLUDGE DRYING BEDS
PRELIMINARY (SEPTIC) SETTLING TANKS
FUTURE SLUDGE DRYING BEDS
FUTURE SETTLING TANKS
LABORATORY
GRIT CHAMBER
Scale

FIG. 15.—General plan of the sewage-treatment plant at Lexington, Ky.

ried out the plant, as a whole, should present a very attractive appearance.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 38.—*Results of chemical analyses at the Lexington (Ky.) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.					Settleable solids, 2 hours, c.c. per liter.[1]				Oxygen consumed 30' in boiling water.				Alkalinity as CaCO₃ by M. O.				Ether soluble matter 24-hour comp., raw.	Chlorine as chlorides.			
	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw supernatant.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.		Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
Aug. 11.	208	142	111	75	20	1.8	Tr.	Tr.	Tr.	38	24	....	9	136	154	....	....	40	75	85	90	87
12.	193	45	25	50	8	2.2	Tr.	Tr.	Tr.	20	11	3	4	124	124	....	83	59	82	85	85	85
13.	176	47	29	44	....	2.2	Tr.	Tr.	Tr.	23	14	6	7	206	186	152	156	61	117	85	85	78
14.	....	....	....	....	....	1.5	Tr.	Tr.	Tr.	22	18	....	8	222	....	....	166	50	78	78	....	78
15.	145	42	20	62	....	1.5	Tr.	Tr.	Tr.	26	24	....	6	211	244	....	155	62	99	99	....	99
16.	116	63	....	63	....	2.1	Tr.	Tr.	Tr.	39	21	13	11	198	208	....	132	46	57	85	....	82
17.	....	....	....	....	....	2.8	0.3	Tr.	Tr.	38	21	7	4	216	160	172	132	96	85	99	107	85
18.	96	40	27	33	....	1.7	Tr.	Tr.	Tr.	36	32	22	8	220	244	156	158	65	117	96	99	71
19.	231	60	25	52	....	6.7	Tr.	Tr.	Tr.	33	31	14	15	228	214	144	134	50	85	107	99	92
20.	203	108	38	40	....	1.9	Tr.	Tr.	Tr.	42	25	12	26	206	208	140	140	54	92	92	92	92
21.	128	53	43	18	....	1.8	Tr.	Tr.	Tr.	38	24	14	10	196	200	150	112	57	89	107	99	99
Average..	166	67	40	48	14	2.4	Tr.	Tr.	Tr.	32	22	11	9.8	196	194	152	137	58	89	92	94	86

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.						Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.			
	Raw.		Effluent Imhoff tank.		Effluent secondary sedimentation tank.		Raw.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
									Per cent concentration.			
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.			10	10	100	100
Aug. 11........	36	128	24	88	2	16	0.0	5.2	46	70	144+	144+
12........	48	136	40	96	2	14	.0	5.2	47	47	144+	144+
13........	72	164	24	64	6	16	.0	5.4	48	50	120+	120+
14........	44	88	44	72	6	18	.3	4.0	72	72	120+	120+
15........	64	136	40	88	1	16	.0	6.2	72	72	120+	120+
16........	56	112	24	60	3	12	.6	5.1	94	94	120+	120+
17........	64	136	44	84	6	19	.1	5.8	48	48	144+	144+
18........	72	124	56	112	5	13	.0	4.1	46	46	120+	120+
19........	140	272	....	120	5	22	.0	4.4	96+	96+	96+	96+
20........	52	....	....	....	....	....	.0	7.2	71	71	72+	72+
21........	....	....	....	....	....	....	....	....	67	48+	48+	48+
Average......	65	144	37	87	4.0	16	.1	5.2	....	....	....	....

[1] Tr. indicates less than 0.1 c. c.

With the exception of the oxygen demand the raw sewage is slightly weaker than the average found on the survey. Though dissolved oxygen is only occasionally present, and then only in small amounts, there is no indication in the physical appearance and odor to indicate that the sewage is septic. In this instance, and in several others encountered during the survey, it is not believed that the dissolved oxygen determination is a true indication of the character of the sewage as sampled. The dissolved oxygen determination was made more as an adjunct to the oxygen demand determination than as a separate determination. It was made, therefore, on the 24-hour composites. While the samples were kept on ice during the entire collection period, it is very possible that a small dissolved oxygen content could be used up during this storage.

The Imhoff tanks, by effecting a removal of 60 per cent of the suspended solids, 30 per cent of the oxygen consumed, and 40 per cent of the oxygen demand constituents, satisfactorily prepared the sewage for oxidizing action of the trickling filters.

The effluents from the trickling filters and that from the secondary sedimentation tanks both showed 100 per cent stability based upon the methylene blue test. Dissolved oxygen was present in comparatively large amounts in the secondary sedimentation tank effluent. The suspended solids from these tanks were higher than from the filters, but this is of no significance, since the solids in the effluent depend upon the frequency with which sludge is removed from these tanks.

Town Branch, the receiving body of water, is not sufficiently large to afford a very high dilution of the plant effluent it receives. In addition, above the treatment plant, an oil refinery discharges a small amount of waste, so that at point of entrance the sewage had, on the day of inspection, a better physical appearance than the water in the stream. Even under these unfavorable conditions the stream is apparently capable of caring for the sewage without creating any nuisance. Even should trouble arise, the oil waste should be eliminated before placing blame on the sewage-treatment plant, which seems to be producing an effluent satisfactory for disposal by the available dilution.

The initial cost involved in putting the treatment plant in operation was $241,100. Of this $39,500 was expended in the construction of the outfall sewer from the city sewer system to the treatment plant, leaving $211,600 for the treatment plant proper. As the bids were submitted and payment made on a unit basis with but few lump-sum items, it is not possible to separate the total cost into the various treatment devices.

Since the original installation $5,062 have been expended in modifications, improvements, enlargements, or additional work. A little over $4,000 of this was spent on the grounds for grading, roadways, and walks.

For maintenance and operation $6,600 was appropriated for 1920. Out of this the superintendent in charge of operation receives $1,800 and the chemist, part time, $900. The only other regular employee is the night watchman. From time to time special labor is employed as needed. It should be noted that the common laborers, of which there are regularly two, are not entered as an expense against the plant. These two laborers, and occasionally two more, are city prisoners farmed out to the county authorities under an agreement by which the sewage-treatment plant is entitled to four laborers. Because of this arrangement the appropriation of $6,600 is too low to be used in comparisons with operating cost data at other plants.

By the accounting system used by the city interest on bonds issued for construction of the outfall sewer and treatment plant is not charged back annually as against these improvements. Nor is any allowance made for depreciation. All clerical work in connection with the plant is done in the engineer's and auditor's office by their departmental clerks, and no charge is made against the plant for this service.

IX. Reading, Pa.

The engineering survey of the sewage-treatment plant at Reading, Pa., was made July 14 to 17, 1920. The laboratory studies followed about a month later, August 6 to 16.

Reading is a city of 114,000 population located in the southeastern part of Pennsylvania on the Schuylkill River. It is an industrial center with a wide range of industries, including soap works, dye works, tanneries, paper mills, hat factories, breweries, and metal-work plants.

The sewerage system of Reading is built on the separate plan. There are no definite data on the amount of infiltration and leakage of storm and ground water into the sanitary sewers, but it is locally considered to be an average amount for sewers of this type. There are no storm overflows on the system and the variation in pumpage does not indicate any excessive infiltration.

All sewers lead to the pumping station where the sewage is screened, as described in detail in Appendix I, and is pumped by 2 R. D. Wood horizontal centrifugal pumps of 6 and 8 m. g. d. capacity, direct connected to 100 and 150 horsepower Westinghouse motors.

The gradients are stated to be very satisfactory, averaging about 0.75 per cent.

Cleaning is done entirely by hose flushing from fire hydrants. There is no regular schedule, and sewers are flushed whenever there is evidence of their needing it.

The total mileage of sewers is 150, of which about 70 are house connections. The following table divides this into the various sizes. Note is made that the 5-inch lines are all house connections.

	Linear feet.
5-inch	314, 248
6-inch	854
8-inch	9, 665
10-inch	402, 467
12-inch	41, 762
15-inch	9, 255
18-inch	5, 840
20-inch	1, 186
24-inch	5, 256
54-inch	2, 862

The city plumbing inspector estimated a total of 11,889 connections to the sewers, and the city officials estimated the contributing population to be 60,000.

The raw sewage is primarily a domestic sewage from separate sewers into which an average amount of infiltration enters. Its character is also altered more or less by industrial wastes. As the maximum travel in the sewers to the pumping station is 2 to 2½ miles, and the time of passage from the pumps to the septic tank at the treatment plant is 40 minutes, the sewage is received at this plant in a fresh condition.

Quite a variety of industrial wastes are tributary to the sewers. Dye waters often change the normal dirty brown color to a dark blue or red or other colors. Felt from a hat factory and some hair from a mattress plant were noticeable in the deposit in the trickling filters. There are also discharged into the sewers tanning wastes, spent metal, pickling liquors, and laundry wastes. One very troublesome waste, the source of which is not known, is received at the pumping station at irregular intervals. It consists of large quantities of a heavy dark grease. At times as much as 3 barrels of this waste has been taken out in one night. It is particularly hard to remove from the screens, and in its emulsified state difficult to burn with the screenings.

The average sewage flow treated at the plant during 1918 was 6.04 m. g. d. Variations were estimated as being a million gallons either way or from 5 to 7 m. g. d. There were stoppages of treatment for 20 days during the year, and there is a wastage during high flows. The amount of this is not known, but, though probably a relatively small percentage of the total if taken over the year, it was sufficient to produce objectionable conditions at its point of discharge on the day of inspection.

The original plans of the treatment plant were prepared by Messrs. Hering & Fuller and Mr. Weand, who also designed the second and third filters constructed. Mr. Ulrich, the present city engineer, designed the last filter installed.

Sewage treatment at Reading dates back to 1895, but the start of the present plant was made in 1907, when Mr. O. M. Weand, who was given a five-year contract for treating the city's sewage,

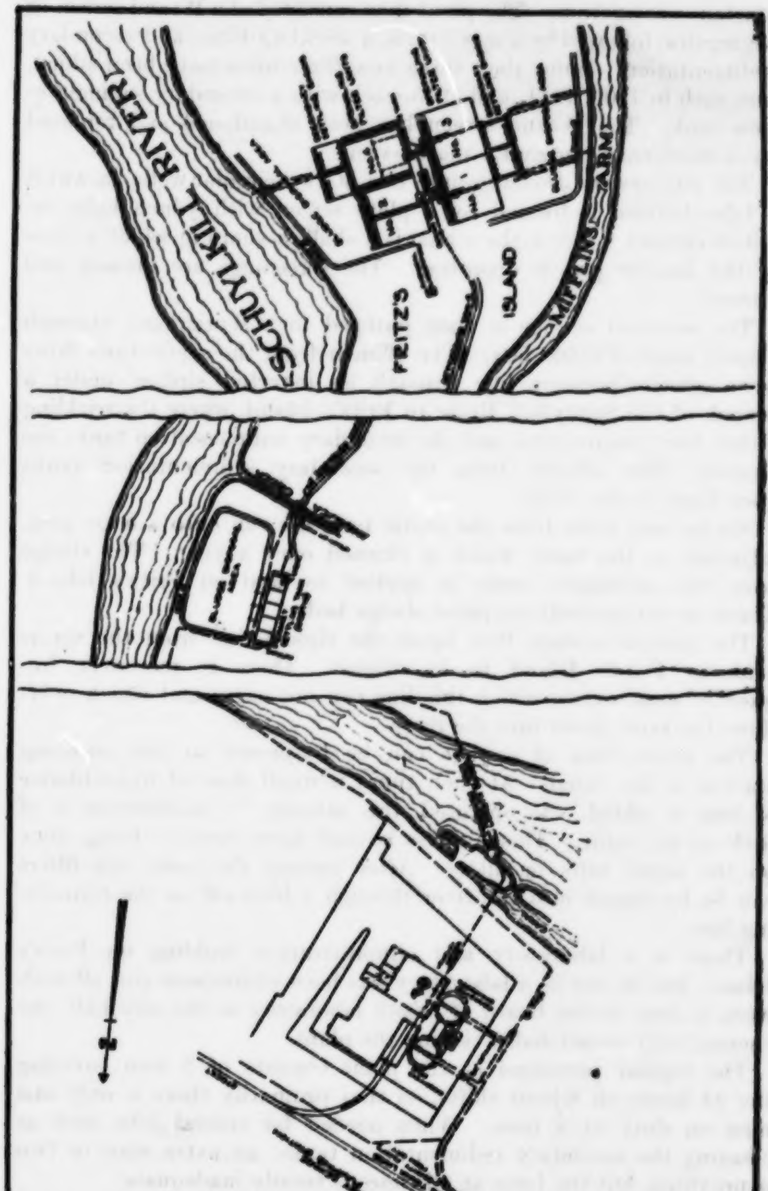
SCHUYLKILL RIVER
FRITZ'S
ISLAND
MIFFLINS ARM

FIG. 16.—General plan of the sewage-treatment plant at Reading, Pa.

started construction. The plant then consisted of a Weand screen or segregator, followed by a septic tank, a trickling filter, and secondary sedimentation. Since then three new filter units have been added, one each in 1909, 1911, and 1915, each with a secondary sedimentation tank. The Weand screen has been abandoned and replaced by a stationary horizontal plate screen.

The city sewers discharge into one of two circular wells, in which a false bottom is formed by a plate screen with ½-inch holes on 2-inch centers. Below the screen is a shallow sump in which a little of the heavier grit is deposited. The screenings are pressed and burned.

The screened sewage is then pumped to a septic tank through a force main of 6,600 feet. The effluent from the septic tank flows by a gravity-pressure line through an inverted siphon under a branch of the Schuylkill River to Fritz's Island, where the trickling filters, four 1-acre units, and the secondary sedimentation tanks are located. The effluent from the secondary sedimentation tanks goes direct to the river.

Sludge and scum from the septic tank are run onto a large area, adjacent to the tank, which is cleaned once a year. The sludge from the secondary tanks is applied to land on Fritz's Island. There are no specially prepared sludge beds.

The present sewage flow taxes the siphon line from the septic tank to Fritz's Island to its utmost. There is, moreover, frequently some excess which this line can not carry and which overflows the tank direct into the river.

The entire flow of sewage can be by-passed at the pumping station to the canal. At such times a small dose of hypochlorite of lime is added. As operated, this attempt at sterilization is of little or no value. This by-pass is used when work is being done on the septic tank or filters. After passing the tank, the filters can be by-passed into the river through a blow-off on the connecting line.

There is a laboratory and administration building on Fritz's Island, but its use as a laboratory has been abandoned and all such work is done in the board of health laboratory in the city hall, the chemist only occasionally visiting the plant.

The regular personnel at the plant consists of 3 men covering the 24 hours on 8-hour shifts, so that ordinarily there is only one man on duty at a time. When needed for special jobs, such as cleaning the secondary sedimentation tanks, an extra man or two is provided, but the force at all times is totally inadequate.

The condition of the grounds reflect the lack of labor. They have the appearance of being semiabandoned after a start was made to park and plant. Mud deposited by high water in the river in the spring of the year has been only partially removed. Considering the working force available, however, it is surprising that the conditions are not worse than they are.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 39.—*Results of chemical analyses at the Reading (Pa.) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.					Settleable solids, 2 hours c. c. per liter.[1]				Oxygen consumed 30' in boiling water.				Alkalinity as CaCO₃ by M. O.				Ether soluble matter 24-hour comp., raw.[3]	Chlorine as chlorides.			
	Raw.	Effluent septic tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw supernatant.	Raw.	Effluent septic tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent septic tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent septic tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.		Raw.	Effluent septic tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
Aug. 6	....	74	30	20	36	....	Tr.	Tr.	Tr.	...	34	18	14	....	189	88	88	20	...	122	118	120
7	....	94	44	28	72	....	Tr.	Tr.	Tr.	...	29	12	10	....	189	90	109	22	...	120	125	120
8	....	68	28	20	47	....	Tr.	Tr.	Tr.	...	27	11	11	....	172	104	96	15	...	78	80	96
9	....	66	32	22	39	....	Tr.	Tr.	Tr.	...	23	12	10	....	184	92	98	16	...	68	78	75
10	....	100	44	18	66	....	Tr.	Tr.	Tr.	...	30	14	13	....	178	108	116	36	...	110	110	110
11	....	74	34	18	82	....	0.3	0.2	Tr.	...	31	18	15	....	180	120	120	18	...	102	105	105
12	....	88	56	34	76	....	Tr.	Tr.	Tr.	...	26	23	16	....	188	120	120	24	...	132	120	128
13	159	118	72	60	66	1.5	Tr.	Tr.	Tr.	43	31	23	18	168	180	120	120	38	125	100	100	100
14	160	100	92	60	70	2.0	Tr.	Tr.	Tr.	51	34	21	18	164	168	116	116	35	120	110	110	110
16	118	66	34	34	28	2.5	Tr.	Tr.	Tr.	42	30	15	15	160	160	89	100	24	115	110	115	115
Average..	145	88	48	31	57	2.0	Tr.	Tr.	Tr.	45	31	16	14	164	177	105	107	25	120	105	107	108

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.								Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.				Nitrogen as nitrates.	
	Raw.[2]		Effluent septic tank.		Effluent trickling filter.		Effluent secondary sedimentation tank.		Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent septic tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
											Per cent concentration.					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.			10	20	100	100		
Aug. 6	......	......	29	54	4.2	8	4.2	6	4.7	4.4	......	120+	120+	[5]120+	6.5	9.5
7	......	......	29	57	3.8	5	2.0	6	4.4	4.0	......	48	120+	120+	7.0	7.5
8	......	......	46	106	5.2	15	2.8	12	4.5	5.1	......	24	120+	120+	3.8	4.0
9	......	......	29	80	3.0	13	2.6	8	5.4	5.0	......	48	120+	120+	5.5	6.5
10	......	......	60	136	10.0	28	5.0	24	3.1	2.8	......	24	120+	120+	4.0	6.0
11	......	......	56	124	10.0	28	7.5	28	3.8	3.9	......	24	120+	120+	1.2	0.9
12	......	......	54	114	14.0	29	4.5	17	0.6	0.0	......	48	120+	120+	2.8	3.0
13	38	128	50	110	11.0	29	9.5	23	4.0	4.3	72	[3]72	120+	120+	2.4	3.2
14	68	108	56	84	16.0	27	10.0	18	4.0	4.1	72	[3]72	96+	96+	2.2	2.8
16	......	......	......	......	......	......	......	......	4.5	4.0	[4]48	48	48+	48+	7.5	7.5
Average..	60	118	46	98	8.6	20	5.4	15	3.9	3.7	......	......	......	......	4.4	5.1

[1] Tr. indicates less than 0.1 c. c. per liter.
[2] Effluent from septic tank (Aug. 6 to 12 incl.).
[3] 10 per cent concentration.
[4] 20 per cent concentration.
[5] 40 per cent concentration.

Only three samples of raw sewage were analyzed. This was because of the difficulty of obtaining and transporting them. The only point at which samples could be obtained was at the pumping station, as the sewage enters the septic tank direct from the force main 5 to 6 feet below the surface of the sewage in the tank. The pumping station is located some 2 miles by road from the septic tank. It was impossible, therefore, for the sample collectors to cover all the desirable sampling points. As it was, they had to walk a distance of a half mile from the filters to get the sample from the septic tank. Toward the end of the studies, however, arrangements were made with the engineer at the pumping station for the collection of the three samples analyzed.

Based on the three samples, the raw sewage appears to be very close to the average obtained on the survey. The suspended solids are about 10 per cent low, but the oxygen consumed and the 5-day oxygen demand are almost exactly the same as the average. It is believed that these results are representative. In 1918 the average for the year for suspended solids and oxygen consumed determinations made by the chemist at the plant were 130 and 50, respectively, neither of which results are far from those discussed above.

The results of the analyses of the effluent from the septic tank require no special comment. They indicate a normal septic tank effluent at a time when it is operating with very little unloading.

The final effluent from the plant, as based on the analyses made, which, with the exception of the nitrates, are in close agreement with those made by the local chemist, is entirely satisfactory for disposal by dilution in the Schuylkill River. The minimum river flow in 1914, when the river was considered unusually low, was 190 second-feet. This is sufficient for a dilution factor of 17 for a very high sewage flow of 7 m. g. d. For a normal sewage flow the least dilution would be about 20, with an average dilution of probably 25–35. Even much smaller dilutions would suffice, as the plant effluent is of a good character, with a low suspended solid content of 31 parts per million, a 5-day oxygen demand of only 15, for which is available in the sewage itself dissolved oxygen and nitrates and nitrites of 3.7 and 5.0 parts per million, respectively. Considering the very limited supervision and attention to operation which the small personnel can give, the character of the effluent is surprisingly good.

Accurate construction costs were not obtainable. The septic tank was made by remodeling an old double-deck filter, and this work, together with some of the filter installation, was done under a lump-sum contract, which also included the operation of the plant. The city in 1918 appraised the entire sewage-treatment system at $426,821.38. This figure, however, includes the pumping station, force main to the septic tank, and other items required by purely local conditions.

The budget estimate of the cost of operation for 1920 was $29,989, but this figure also includes the pumping station, where probably

96a

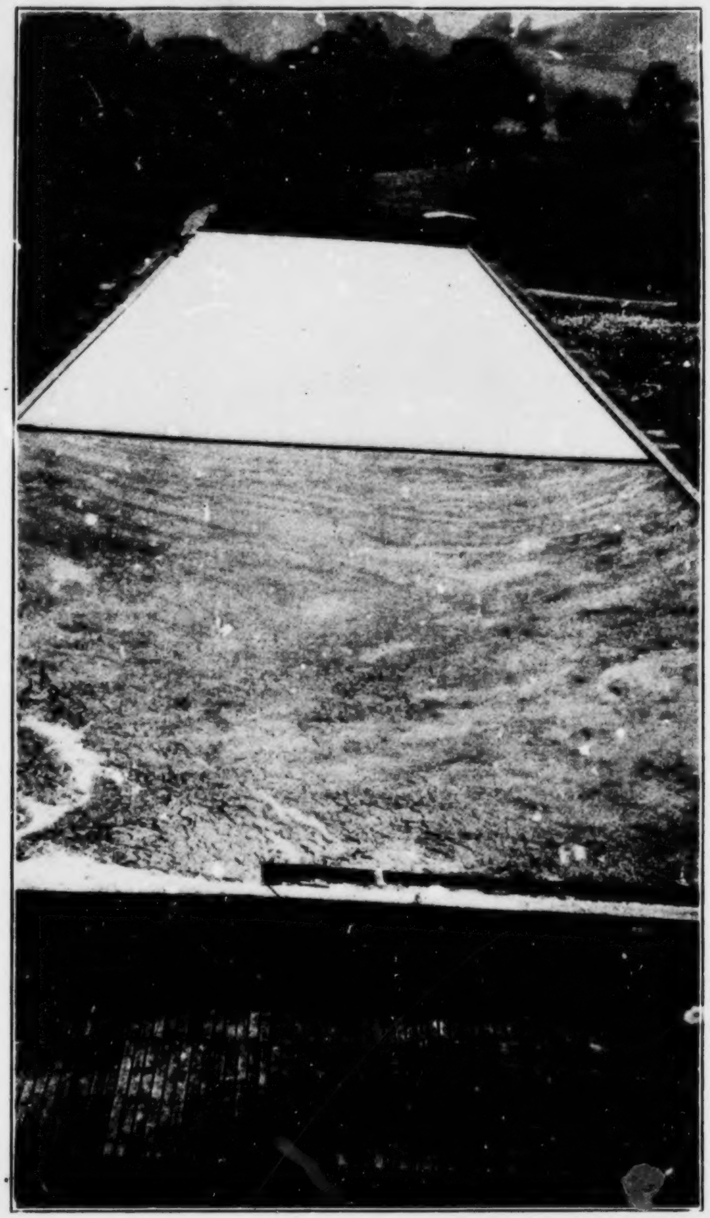

FIG. 17.—SEPTIC TANK AT READING, PA., SHOWING MOVABLE BAFFLE WITH SCUM AHEAD AND CLEAR SURFACE BEHIND.

two-thirds of the total appropriation is spent. It is not fair to compute from it the cost of treatment alone.

X. Rochester, N. Y.

At Rochester, N. Y., two plants were surveyed which were so different in design and operation that it is not possible to discuss them together, as was done with the two plants at Atlanta, Ga., and Houston, Tex. The sewerage system and raw sewage also require separate treatment. With the exception, therefore, of the general statement of the size and character of the city as a whole, the treatment plants will be taken up separately.

Rochester is a city of 296,000 population, located in the northwestern part of New York on Lake Ontario. It is primarily an industrial city containing many large plants engaged in the manufacture of a wide range of products. The majority of these, however, do not produce liquid wastes. The residential sections are, for the most part, very attractive.

A. BRIGHTON SEWAGE TREATMENT PLANT.

The engineering survey of the Brignton sewage treatment plant at Rochester, N. Y., was made June 21 to 23, 1920. The laboratory studies followed one month later, July 16 to 24.

The sewerage system tributary to the plant is of the strictly sanitary type, there being very few, if any, roof drains and no other storm drains connected. Infiltration is, however, considered to be high. No exact data are available regarding its volume, but it is estimated to run 25 to 50 per cent of the total sewage flow.

Topography permits the uniform use of good grades, 0.5 per cent being the flattest used.

The total mileage of sewers is 20, divided as follows:

	Linear feet.		Linear feet.
8-inch	83,453	18-inch	3,517
10-inch	5,992	20-inch	975
12-inch	3,910	24-inch	4,340
15-inch	3,618		

To these there are 1,215 sanitary connections, serving an estimated population of 8,000, or 6.4 persons per connection.

All flushing is done by automatic flush tanks which are located on all dead ends and at points where the velocity of flow, when the sewers are running one-half full, is less than five feet per second.

Mention may be made of a small pumping plant consisting of two 50-gallon Pacific Flush Tank Co.'s automatic ejectors, which serve a very small section in the tributary area; in fact, only one house was connected to this system at the time of inspection, June, 1920.

There is one overflow point on the entire system of tributary sewers, and this one is said to operate but rarely. It is also available and can be used as a complete by-pass around the treatment plant.

The raw sewage is strictly domestic, with no surface storm waters and negligible amount, if any, of industrial wastes. There is, however, considerable dilution by infiltration, which, as already stated, is estimated to amount to at least 25 per cent and probably 50 per cent of the entire flow.

The tributary area is comparatively small, and all within a relatively short distance from the plant, so that the sewage has not far to travel. It is, therefore, quite fresh. This is indicated by the unbroken condition of the suspended solids and the odor typical of fresh sewage.

The volume of sewage is measured over a trapezoidal weir at the outlet of the plant. There is an indicating but not a recording device, so that readings are taken three times daily, at 7.30 a. m., 12 noon, and 5 p. m. No readings are taken during the night as there is no one at the plant after 5 p. m.

The average flow for the year 1918 was 1.02 m. g. d. This figure may be in excess of the actual amount, due to the fact that it is based on the day readings and fails to take in the lower night flows. The lowest 24-hour flow in 1918 was 0.71 m. g., occurring on January 31, and the highest flow was 1.76 m. g., occurring on February 15.

The treatment plant was designed by John F. Skinner, principal assistant engineer in the city engineer's office. The plans were approved by F. T. Elwood, former city engineer, and E. A. Fisher, consulting engineer, and the general method of disposal was passed upon by George C. Whipple. Bids were received for construction in April, 1915, and actual operation of the plant started March 1, 1916.

The main sewer to the plant discharges into a channel from which it was originally planned to take sewage through one of three parallel baffled grit chambers. As actually operated, however, one of the original [illegible] has been converted into a [illegible] and [illegible] is used [illegible] of the time, [illegible] chamber [illegible] read [illegible] wash out in a [illegible] might be carried [illegible] passe[illegible] under a [illegible] on [illegible] there [illegible] a discharge chamber. [illegible] either through a [illegible] pipe to [illegible] the operating house, or through a 12-inch overflow pipe to the operating house and thence to the Imhoff tanks. The grit chambers, screens, etc., are housed in an attractive tapestry brick building.

All sewage is settled in an Imhoff tank which is designed with parallel sides but semicircular ends. There are inlet and outlet scum boards but no other baffles. The inlet and outlet channels are arranged to permit the reversing the direction of flow through the tank.

The effluent channel from the Imhoff tank carries the sewage to a triangular siphon chamber, which contains the siphons discharging into the dosing tanks of the trickling filters.

18a

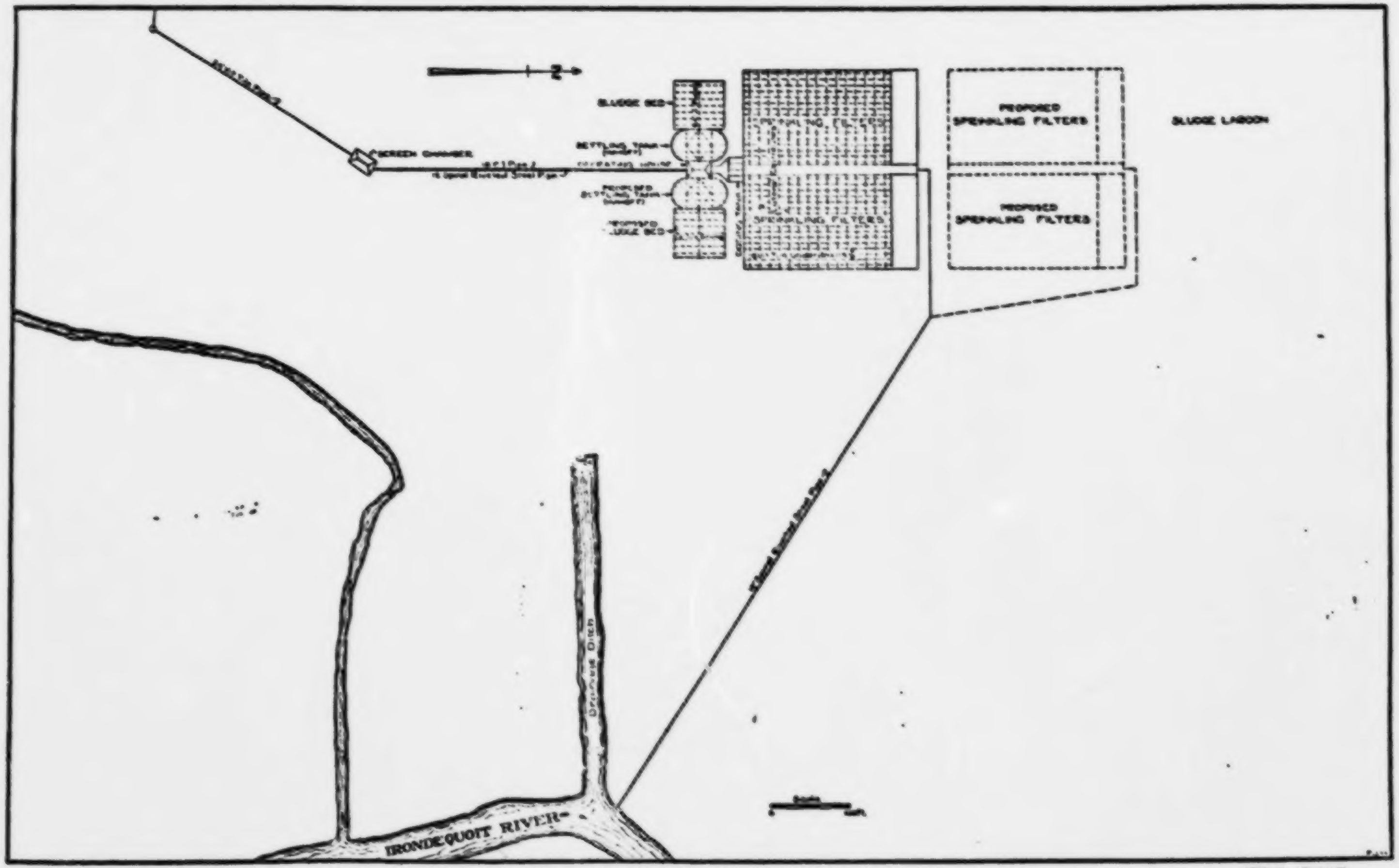
N
SCREEN CHAMBER
SLUDGE BED
SETTLING TANK
PROPOSED SETTLING TANK
PROPOSED SLUDGE BED
SPRINKLING FILTERS
SPRINKLING FILTERS
PROPOSED SPRINKLING FILTERS
PROPOSED SPRINKLING FILTERS
SLUDGE LAGOON
DRAINAGE DITCH
IRONDEQUOIT RIVER
Scale

FIG. 18.—General plan of the Brighton sewage-treatment plant at Rochester, N. Y.

2612—13. (Face p. 38.)

98-b

FIG. 19.—THE BRIGHTON PLANT AT ROCHESTER, N. Y.

The filter area is divided into two units, each operated by a separate dosing tank, as mentioned above. The effluent from the filters is collected in two secondary sedimentation tanks, one for each filter, from which the final effluent pipe carries the sewage to a submerged outlet in the Irondequoit River.

Two underdrained specially constructed sludge beds are located just west of the Imhoff tanks. These have not, however, been used for the past two years, as it has been found more advantageous to dispose of sludge in a low lagoon about 500 feet north of the tank, but well concealed from the plant by trees and other growth.

There are no laboratory facilities located at the plant itself. All such work is done at the other sewage-treatment plant. Here the laboratory is very well equipped, but during the past season little, if any, chemical work has been done. Three laborers maintain the regular operation of the plant during the day, there being no one on duty at night. In addition, extra labor is furnished from time to time for handling sludge, road work, grading, and special jobs.

Few plants are located in such favorable natural surroundings or give evidence of as careful and intelligent care of the grounds as is the case at this plant. Their general appearance disguises, even to the average prejudiced mind, the real purpose of the plant to such an extent that they are frequently used for picnics.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 40.—*Results of chemical analyses at the Rochester Brighton sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.	Suspended matter.					Settleable solids, 2 hours, c. c. per liter.[1]				Oxygen consumed 30′ in boiling water.				Alkalinity as CaCO₃ by M. O.				Ether soluble matter 24-hour comp., raw.	Chlorine as chlorides.			
	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw supernatant.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.		Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
July 16.	107	42	24	11	23	2.0	Tr.	Tr.	Tr.	18	10	6.4	4.0	184	186	108	130	14	42	43	42	42
17.	88	22	44	12	33	2.5	Tr.	Tr.	Tr.	34	15	7.7	5.4	145	190	140	125	15	46	44	44	44
18.	76	28	20	13	.....	1.5	Tr.	Tr.	Tr.	28	15	10.0	6.8	175	182	128	125	12	42	45	42	40
19.	134	40	24	4	18	1.5	Tr.	Tr.	Tr.	18	9	8.0	6.8	200	200	140	135	18	42	45	45	45
20.	144	70	28	22	28	3.0	Tr.	Tr.	Tr.	22	22	9.8	7.2	185	190	135	130	22	68	45	46	42
21.	84	44	40	4	16	1.5	Tr.	Tr.	Tr.	22	16	13.0	5.9	180	180	135	135	12	45	45	45	48
22.	94	40	28	8	13	2.0	Tr.	Tr.	Tr.	30	16	15.0	7.1	170	195	130	125	18	39	45	46	45
23.	80	38	20	8	11	2.0	Tr.	Tr.	Tr.	16	17	8.2	4.6	185	190	130	130	14	41	45	42	42
Average.	101	40	29	10	18	2.0	Tr.	Tr.	Tr.	24	15	9.7	5.9	178	189	131	131	16	45	45	44	44

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[1] Tr. indicates less than 0.1 c. c.

Table No. 40.—*Results of chemical analyses at the Rochester Brighton sewage-treatment plant*—Continued.

24-hour sample ending 8 a.m.—	Biochemical oxygen demand at 20° ± C.								Dissolved oxygen.			Hours to reduce M. B. at 20° ± C.				Nitrogen as nitrates.	
	Raw.		Effluent Imhoff tank.		Effluent trickling filter.		Effluent secondary sedimentation tank.		Raw.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Raw.	Effluent Imhoff tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.	Effluent trickling filter.	Effluent secondary sedimentation tank.
												Per cent concentration.					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.				10	20	100	100		
July 16	20	40	8	20	2.0	7.2	1.0	4.6	0.3	8.0	9.0	120	120+	120+	120+	3.5	4.2
17	36	142	9	34	1.7	7.2	1.5	5.7	......	7.6	8.7	48	72	192+	192+	4.0	4.3
18	22	55	10	36	2.1	6.9	1.7	5.1	3.9	7.5	7.9	[1]48	[1]72	192+	192+	3.0	3.6
19	14	56	8	32	2.1	7.5	1.2	5.9	4.6	7.8	8.0	70	192+	192+	192+	1.4	0.8
20	22	96	31	72	3.3	......	2.6	......	.4	7.0	7.5	28	28	168+	168+	1.8	1.6
21	26	66	8	40	2.8	......	1.5	6.4	2.3	6.5	7.4	120	52	144+	144+	2.7	2.6
22	14	65	8	32	1.6	7.0	1.0	4.4	3.4	6.8	7.9	120	120+	120+	120+	2.2	2.2
23	14	60	12	34	2.1	7.3	1.3	4.9	4.6	7.5	8.2	120+	120+	120+	120+	3.6	4.4
24	22	58	6	24	3.6	7.1	2.3	5.0	4.4	7.8	7.9	72	120+	120+	120+	......	......
Average	22	67	11	36	2.5	7.1	1.6	5.2	2.7	7.4	8.0	......	......	......	......	2.8	2.9

[1] 40 per cent concentration.

The raw sewage is unusually weak, probably due to the large percentage of infiltration water it contains. This dilution is particularly noticeable in the chlorine content, which is only about one-half the next lowest value obtained in these studies. All other determinations upon which the concentration of a sewage may be judged are also low. With the exception of the 5-day oxygen demand which is lower at the Atlanta plants, and equaled at San Marcos, the values obtained in the other critical determinations are the lowest found during the survey. That the sewage is exceptionally fresh is evidenced by the high value of the dissolved oxygen. This constituent too, is materially affected by the ground water of infiltration.

Few plants have as large a margin of safety against any possible nuisance from the final effluent as has this one. The character of the effluent is exceptionally high, well above the average found in the survey, the dissolved oxygen content alone being over 50 per cent higher than the 5-day demand. There is no danger of any deposition of the 10 parts per million of suspended solids.

In addition to the character of the effluent itself, the dilution in the Irondequoit River is always very high. The only evidence of sewage entering the river at the point of discharge on the day of inspection was an agitation in the water and the bulkhead on the shore.

The total cost of the construction of the plant was $119,451, divided as follows:

A. Site with pipes, outlet, etc	$28,708
B. Screen house and grit chambers	6,164
C. Imhoff tank, sludge beds, and operating house	19,499
D. Dosing device, trickling filters, and secondary tanks	57,819
E. Power development, electrical and mechanical equipment, laboratory equipment	7,261
Total	119,451

It is not possible to compute from these figures a fair cost per million gallons, since much construction work is completed for a plant double the capacity of the present one. Thus the filter gallery, part of the dosing device, the grit chambers, screen house, and other buildings have been built complete for an estimated future growth of the plant.

In the 1919 annual report of the engineer and chemist in charge of operation of the plant the following summary of maintenance and operating costs is made:

Superintendence	$187.50
Labor	2,555.60
Maintenance supplies, repairs, telephone, water	372.93
Total	3,116.03

On the basis of 390 million gallons treated during that year, the cost per million gallons is $7.90. In addition to the above expenditures, the park department spent in labor of the park gang $3,420.30. This was for the maintenance of the park grounds around the treatment plant.

B. IRONDEQUOIT SEWAGE-TREATMENT PLANT.

The engineering survey of the Irondequoit sewage-treatment plant at Rochester, N. Y., was made June 17 to 22, 1920. The laboratory studies followed one month later, July 14 to 30.

The sewerage system tributary to the plant is of the combined type. It is estimated to serve a population of 240,000. Infiltration is estimated to amount, on an average, to about 2 m. g. d. for the entire system.

The topography allows good grades for the most part, averaging 0.5 per cent. The minimum is considered sufficient to insure self-cleaning velocities, and no direct flushing of any nature is done. Data covering the mileage of the various size pipes or the mileage of the entire system were not available.

There are eight storm overflows on the system which operate when the flow becomes three and one-half times the dry weather flow. The dry flow accepted for the design of the overflows was 34 m. g. d. so that the rate would reach 120 m. g. d. before there is any overflow. Since the design several of the districts have built up and the overflow control has been readjusted to allow for the increased flow.

To collect and remove the grit in the sewers there are installed two sand catchers. These are ahead of the inverted siphons which carry only one-half the total sewage flow. From both of them the total removal in 1919 was 3,189 cubic feet, or an average of 9 cubic feet per day. With an average flow of over 17 m. g. d. during the year, the grit removed amounts to less than 0.6 of a cubic foot per million gallons, which is only a very small per cent of the total carried by the sewage.

The raw sewage received at the treatment plant is of the combined type. There is a considerable period of travel in the sewers, and the sewage reaches the plant in a stale condition. The suspended solids are pretty well broken up and water-soaked. Matches and small sticks were observed floating on the surface and pieces of paper, fecal matter, fruit and vegetable seeds, and skins suspended in the sewage.

Industrial wastes are practically negligible. A small dye plant and a slaughterhouse are connected to sewers tributary to the plant, but the waste is treated before entering the sewers. The dye-plant wastes at times impart a distinct color to the sewage, but, so far as ascertainable, do not affect the treatment processes.

The average dry-weather flow is 32 to 33 m. g. d. and the maximum flow at the plant for any one day from January, 1918, to April, 1920, both inclusive, was 59.64 m. g. The maximum rate of flow has been over 150 m. g. d. This exceeds the original design, but is due to adjustments of the regulating devices to control increased dry flows.

The plant, situated on Lake Ontario, serves all the city except a relatively small section tributary to the Brighton plant, and also the Charlotte, Skunk Hollow, and Maplewood territories to the north and west.

The sewage is measured on entering the plant by a recording Venturi meter. The first treatment device consists of coarse bar screens with 3-inch clear openings at the entrance to the grit chambers. Six of these are in place, but only four used to any extent, the other two being available for by-passing around the fine screens which follow the grit chambers. The grit chamber installation is sufficient for future growth of the plant to double its present capacity. A traveling "A" crane derrick excavator with a clam-shell bucket is used for cleaning. Grit is removed without draining the chambers and, during the winter, without interference to continuous operation.

From the grit chambers the sewage passes to Riensch-Wurl screens 12 feet in diameter. There are four of these in place, each served by a separate grit chamber as influent channel. These screens are housed in a large attractive brick building which also contains the work shop, laboratory, toilets, etc.

From the screens the sewage enters the influent channels of the Imhoff tanks, of which there are ten arranged in five units of two

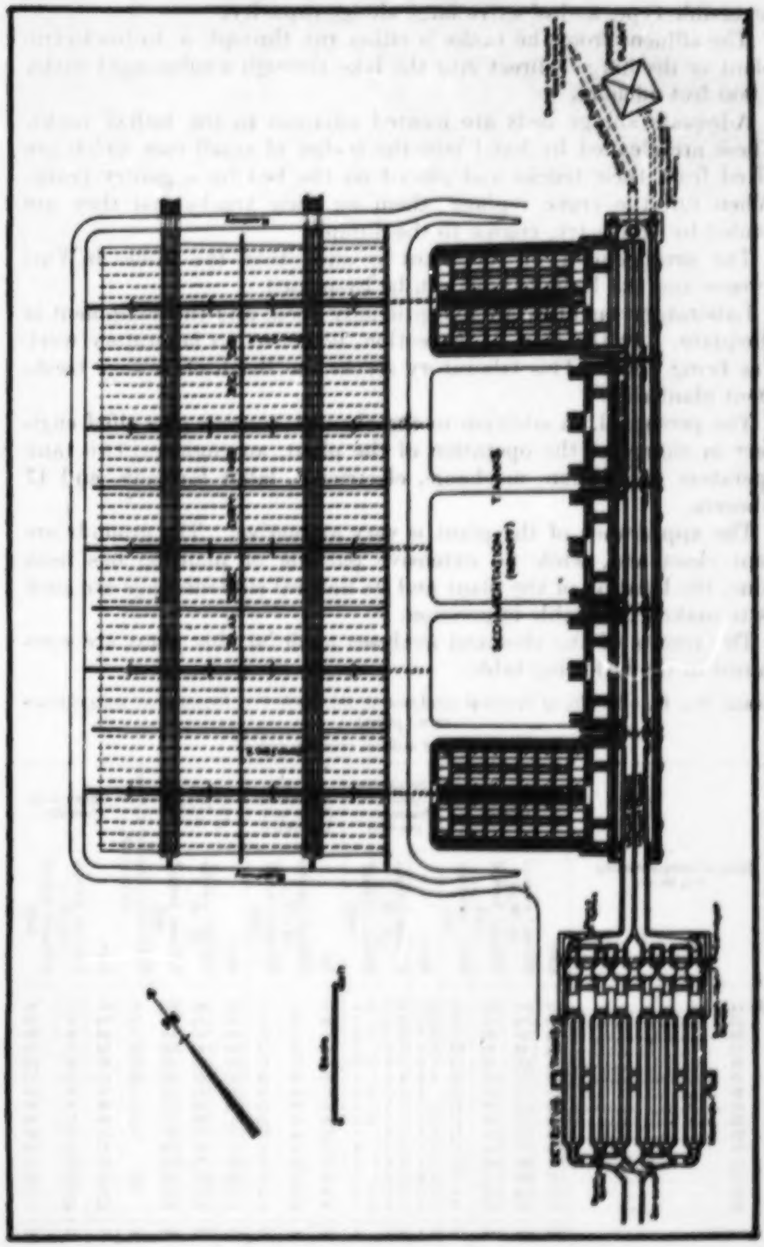

FIG. 38.—General plan of the Irondequoit sewage-treatment plant at Rochester, N. Y.

each. These tanks are rectangular, of the double flow chamber, reversible type, and of extra large sludge capacity.

The effluent from the tanks is either run through a hydroelectric plant or discharged direct into the lake through a submerged outlet 7,000 feet offshore.

Adequate sludge beds are located adjacent to the Imhoff tanks. These are cleaned by hand into the bodies of small cars which are lifted from their trucks and placed on the bed by a gantry crane. When full the crane replaces them on their trucks and they are hauled by an electric engine to the dump.

The arrangement of the plant is such that the Riensch-Wurl screens and the Imhoff tanks can be by-passed.

Laboratory facilities are exceptionally good, and the equipment is adequate. At the time of inspection, however, no laboratory work was being done. This laboratory serves the Brighton sewage treatment plant also.

The personnel, in addition to the chemist, consists of a chief engineer in charge of the operation of the plant, an engineer, two tank operators, relief man, mechanic, electrician, labor foreman, and 17 laborers.

The appearance of the plant is very attractive. The grounds are kept clean and, while no extensive parking or planting has been done, the location of the plant and its natural surroundings are such as to make a favorable impression.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 41.—*Results of chemical analyses at the Rochester Irondequoit sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.				Settleable solids, 2 hours, c. c. per liter.			Oxygen consumed 30° in boiling water.			Alkalinity as CaCO₃ by M. O.			Ether soluble matter 24-hour comp., raw.	Chlorine as chlorides.		
	Raw.	Effluent screens (R.-W.).[1]	Effluent Imhoff tank.	Raw supernatant tank.	Raw.	Effluent screens (R.-W.).[1]	Effluent Imhoff tank.	Raw.	Effluent screens (R.-W.).[1]	Effluent Imhoff tank.	Raw.	Effluent screens (R.-W.).[1]	Effluent Imhoff tank.		Raw.	Effluent screens (R.-W.).[1]	Effluent Imhoff tank.
July 14	128	164	110	37	2.0	2.0	0.4	29	38	74	184	180	192	49	88	91	91
15	160	194	178	59	2.0	2.5	.7	40	46	44	174	174	184	24	84	90	94
16	108	128	94	39	2.5	2.7	1.0	35	24	25	184	181	204	27	90	90	90
17	104	94	82	65	1.0	1.5	.1	33	32	24	182	197	200	21	84	85	88
18	154	202	88	24	3.0	3.0	1.5	30	31	42	190	180	180	36	90	95	90
19	198	372	134	20	4.5	4.5	.1	60	56	28	149	180	181	30	65	70	75
20	110	112	110	58	.8	1.5	1.2	41	44	29	184	186	186	75	95	86	88
21	102	124	120	42	1.5	1.5	.5	26	48	33	184	186	186	20	88	90	90
22	364	200	144	54	4.2	1.5	1.1	40	47	28	180	180	180	34	90	75	85
23	144	124	100	44	1.5	1.5	.1	32	54	33	173	172	186	21	90	90	90
24	78	310	140	41	2.0	2.5	.4	41	31	30	143	148	168	....	75	75	80
26	297	293	148	110	1.1	1.4	.1	21	35	27	176	176	186	....	80	87	80
27	197	204	118	60	2.0	2.0	.7	41	42	32	184	184	185	28	90	80	89
28	133	134	132	44	2.0	2.2	1.0	20	28	31	176	174	180	31	75	75	83
29	141	145	109	37	2.0	2.2	1.1	30	46	42	186	186	186	....	84	92	92
Average	165	186	118	50	2.1	2.3	.7	30	44	35	175	175	180	34	82	82	88

[1] [illegible]-inch screen used July 14-18, inclusive; [illegible]-inch, July 19-23, inclusive; $\frac{1}{16}$-inch, July 24-29, inclusive.

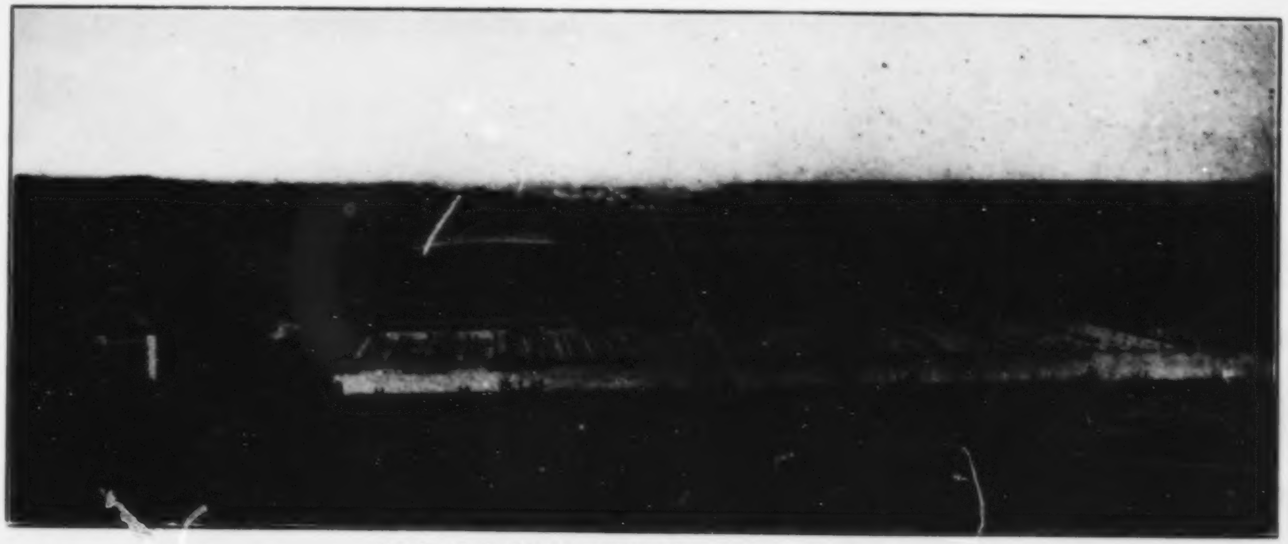

FIG. 21.—THE IRONDEQUOIT PLANT AT ROCHESTER, N. Y.

Excavation in the foreground is in preparation for possible duplication of tanks to the right of the channels.

Table No. 41.—*Results of chemical analyses at the Rochester Irondequoit sewage-treatment plant*—Continued.

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.						Dissolved oxygen, raw.	Hours to reduce M.B. at 20° ± C.					
	Raw.		Effluent screens (R.-W.).[1]		Effluent Imhoff tank.			Raw.		Effluent screens (R.-W.).[1]		Effluent Imhoff tank.	
								Per cent concentration.					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.		10	20	10	20	10	20
July 14	45	106	66	120	32	76	9.0	120	[2]120+	120+	......	120+	......
15	52	76	44	92	36	80	3.6	96	72	120	......	120+	72
16	48	116	28	140	36	80	1.9	120+	96	120+	......	120+	72
17	44	108	44	104	36	76	.0	......	48	......	48	......	72
18	60	......	56	140	40	108	.0	......	48	......	48	......	48
19	28	160	36	104	16	76	.4	......	47	......	47	......	168+
20	40	120	40	100	28	96	.0	......	23	......	23	......	28
21	36	96	56	108	28	80	.0	72	24	144+	......	144+	48
22	48	96	32	100	24	44	.0	120	......	120	......	120	......
23	44	96	44	84	36	64	1.6	96	......	120	......	120+	......
24	40	76	40	72	28	64	.0	120+	......	120+	......	120+	......
25	24	52	16	44	12	36	2.2	72	......	120+	......	120+	......
27	48	156	48	96	28	76	4.4	72	......	96+	......	96+	......
28	......	......	......	......	......	......	.0	96+	......	96+	......	96+	......
29	......	......	......	......	......	......	.0	48	......	48	......	48	......
Average	45	104	42	100	30	74	.9	......	......	......	......	......	......

[1] ¼-inch screen used July 14-18 inclusive; ⅛-inch, July 19-23 inclusive; $\frac{1}{16}$-inch, July 24-29 inclusive.
[2] 5 per cent concentration.

The raw sewage is about the average of those studied on this survey. The suspended solids are a little high, but the oxygen consumed slightly lower than the average. The presence of dissolved oxygen in six of the nine samples analyzed, and in several of these samples in fairly large amounts, seems to contradict the statement previously made that the sewage was stale. The statement referred to normal dry weather flow, and not to conditions of storm flow, which existed at the time the samples showing the dissolved oxygen were taken.

The interesting feature of this plant and the primary reason for its selection for study were the Riensch-Wurl screens. These are discussed in considerable detail in another section of this report, but it is of interest at this point to call attention to the increase of 10 parts per million in the suspended solids after passing the screens. Similar results have been obtained elsewhere, and it is believed to be due to imperfect methods of sampling and analysis, the coarse particles which are removed by the screens not being included in a sample taken for the suspended solids determination by the Gooch crucible. Comparing the results of other determinations on the screen effluent with those for raw sewage, it is found that they are almost identical. From the analyses the action of these screens as a treatment device is negligible. For further discussion of screens, and their efficiency as based on the volume of the screenings removed, reference is made to page 168.

At this plant the final effluent is that from the Imhoff tanks. As the ultimate disposal is by dilution in Lake Ontario where the dilution factor is tremendous, the primary function of the treatment plant is to remove large floating particles that might cause surface nuisance on the lake or be washed ashore and create objectionable conditions there. As judged by the analyses in the above table, the efficiency of the Imhoff tanks is below normal, the removal of suspended solids being only about 40 per cent and the settleable solids 69 per cent. The solids are, however, of such character that they do not create objectionable conditions in the lake or on the shores. Several attempts have been made to locate the outlet in the lake with boats, but they have all been unsuccessful.

The total cost of the construction of the plant was $988,500. This figure, however, includes the hydroelectric installation, which, while introducing possible economies in operation, is not an integral part of the treatment plant. The cost of the outfall sewer from the city to the plant is not included in the above figure.

The operation and maintenance cost for the year 1919 are given as $30,809, divided roughly as follows:

Salaries	$12,519
Labor	12,065
Supplies and materials	6,225

XI. SAN MARCOS, TEX.

The engineering survey of the sewage treatment plant at San Marcos, Tex., was made August 25 to 27, 1920. The laboratory studies followed about two and a half months later, November 3 to 12.

San Marcos, Tex., is a town of about 5,000 population, located on the San Marcos River in the eastern part of Texas, between Austin and San Antonio. It is primarily a trading point for the surrounding agricultural districts, there being no industries of any size. The State normal school is located here, and considerable of the population is centered in this institution.

The sewerage system is entirely of the separate type, with probably a few roof drains illegally connected.

Infiltration and leakage factors were not ascertainable. It was stated by Mr. Wilson, manager of the Utilities Co., that infiltration was probably not large, but that there was considerable leakage through manhole covers. At any rate very heavy storms effect temporary increase in flow.

No data were obtainable covering the sizes or mileage of the sewers included in the sewerage system. The grades were stated to be quite steep, so that very little flushing and draining is necessary. There are 23 automatic flush tanks on the system.

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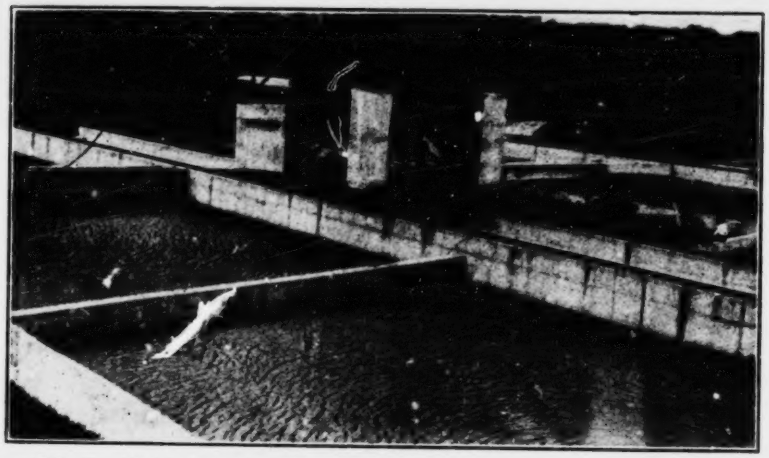

FIG. 22.—SLUDGE BEDS AT THE IRONDEQUOIT PLANT AT ROCHESTER, N. Y.

The sewerage system as well as the treatment plant is owned by the Sewer Co. of San Marcos, and charges are made for individual connections and service. Connection to the sewers, even where available, is not compulsory. As a result only about one-half of the population of about 5,000 is estimated as served by the sewers through 366 connections.

There are no specially prepared overflows on the system, but at the entrance to the treatment plant the sewage passes through a small box which has, at times of heavy rains, overflowed, the sewage running over the ground to the river about 20 feet distant.

The raw sewage is typically domestic, fresh, and diluted by some ground water that is constantly entering the sewers by infiltration. During wet weather, this, with the leakage through manhole covers and a few connected roof drains, probably constitutes a fairly high percentage of the total flow. There are no industrial wastes entering the sewers.

No measurements of flow are made by the local officials, but they estimate it at 60 gallons per capita, per day, for a population of 2,500. During the period covered by the laboratory studies a 12-inch weir was installed at the outlet of the treatment plant and readings taken hourly. These measurements showed variations from 168,000 to 256,000 gallons per day, with an average of 203,000. This is equivalent to 80 gallons per capita for the estimated contributing population of 2,500.

The sewage treatment plant is located just across the San Marcos River and about one-half mile distant from the center of the town.

The present plant was designed by Ashley F. Wilson, and put into operation in 1916, replacing a plant consisting of sedimentation and broad irrigation. At the present time, the sedimentation tank of the old plant is embodied in the new plant.

The sewage first enters the sedimentation tank operated as a septic tank. This is circular and of large capacity in proportion to the flow. The sewage, however, does not flow across the tank but leaves at a point not far from the inlet. The outlet is surrounded by a box covered with a galvanized-iron mesh screen.

From the septic tank the sewage passes to the aeration tank consisting of four channels in series with filtros blocks for aerators. The effluent from this tank goes to the final sedimentation tank, and thence to the San Marcos River.

There is no sludge reaeration tank, the sludge from the final sedimentation tank passing directly back to the inlet of the sewage aeration tank.

Sludge disposal has presented little difficulty. Two beds, 12 feet square, are provided for sludge from the activated sludge process. In addition, some adjacent low lying land has received several applications of sludge. The septic tank has been cleaned only once in the past three years, at which time the sludge was pumped onto the land formerly used for broad irrigation.

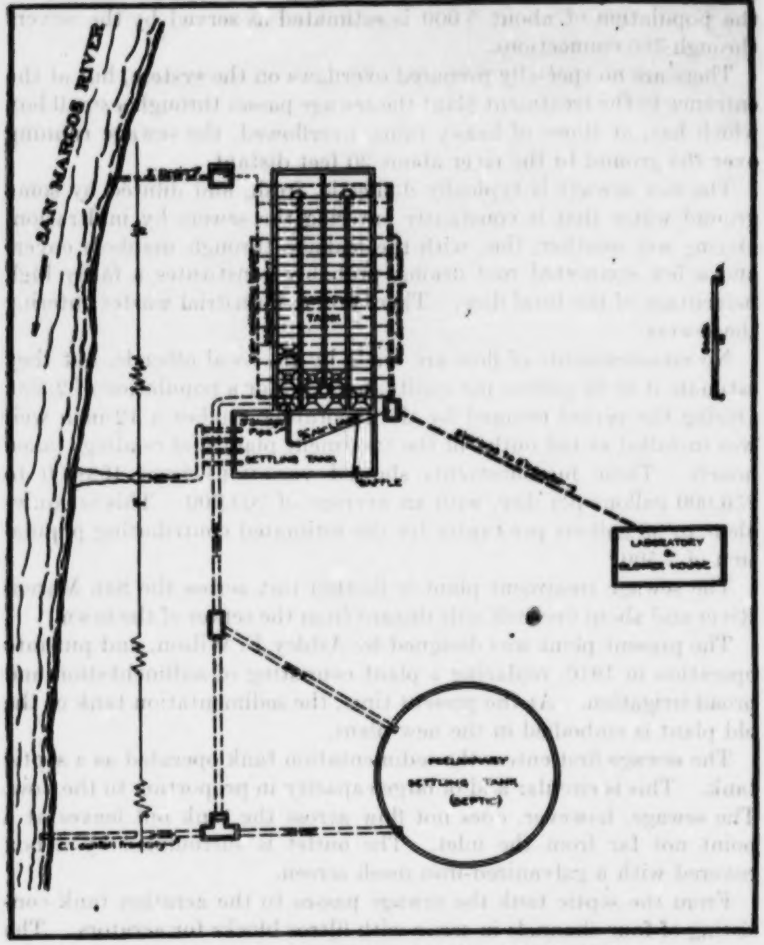
SAN MARCOS RIVER
LABORATORY & BLOWER HOUSE
SETTLING TANK
PRELIMINARY SETTLING TANK (SEPTIC)
TANK
C. I. outfall

FIG. 23.—General plan of the sewage-treatment plant at San Marcos, Tex.

There are no laboratory facilities and no analytical work is done. One man gives part time to the plant, visiting it once or twice a day primarily to oil the motors and blowers. When there is special work to do, extra labor is provided.

No effort has been made to improve the grounds; but they are kept clean, and there is nothing objectionable about the plant.

The results of the chemical analyses made at this plant are contained in the following table:

TABLE No. 42.—*Results of chemical analyses at the San Marcos (Tex.) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.				Settleable solids, 2 hours c.c. per liter.[1]		Oxygen consumed 30' in boiling water.			Alkalinity as $CaCO_3$ by M. O.			Ether soluble matter 24 hours comp., raw.	Chlorine as chlorides.		
	Raw.	Effluent septic tank.	Effluent final sedimentation tank.	Raw Supernatant.	Raw.	Effluent septic tank.	Raw.	Effluent septic tank.	Effluent final sedimentation tank.	Raw.	Effluent septic tank.	Effluent final sedimentation tank.		Raw.	Effluent septic tank.	Effluent final sedimentation tank.
Nov. 3					2.0	Tr.				300	316	236		75	95	95
4					2.2	Tr.	36	24	14.0	301	316	214		82	82	82
5					3.0	Tr.	34	18	9.2	348	324	248		90	75	80
6					2.5	0.3	40	18	7.6	301	308	240		115	115	105
7					2.0	Tr.	30	17	8.8	304	304	236		75	97	97
8	120	28	8.0	16	3.0	Tr.	31	17	8.0	308	312	232		82	90	90
9	116	84	.0	8	2.5	Tr.	25	19	7.6	304	308	228		90	90	90
10	96	12	.0	8	2.0	.3	26	17	6.8	296	304	236		95	95	95
11	68	28	8.0	12	2.0	Tr.	23	20	8.8	298	308	236		70	75	80
12	148	60	.0	4	1.6	Tr.	18	12	5.6	296	312	228	[2]18	55	65	75
Average	110	42	3.2	10	2.2	Tr.	29	18	8.5	305	311	230	[2]18	83	88	89

24-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.						Dissolved oxygen.			Hours to reduce M. B. at 20° ± C.			Nitrogen as—		
	Raw.		Effluent septic tank.		Effluent final sedimentation tank.					Raw.	Effluent septic tank.	Effluent final sedimentation tank.	Ammonia.		
										Per cent concentration.					
	1-day.	5-day.	1-day.	5-day.	1-day.	5-day.	Raw.	Effluent septic tank.	Effluent final sedimentation tank.	10	10	100	Influent aeration tank.	Final effluent.	Nitrates effluent final sedimentation tank.
Nov. 3	36	70	24	56	3.5	22.0	4.0	3.1	7.1	144	144+	144+	18	4.8	9.6
4	34	94	18	58	5.3	22.0	3.5	4.9	7.4	96	120+	120+	18	4.8	8.8
5	30	72	20	58	3.3	18.0	2.7	4.4	7.9	120	192+	192+	16	2.2	7.2
6	36	58	24	62	3.5	16.0	1.0	.8	6.7	72	168+	168+	12	2.8	14.0
7	36	80	28	54	3.8	18.0	1.4	2.3	7.5	72	144+	144+	17	4.4	7.2
8	26	52	26	62	2.7	8.4	2.1	2.0	7.6	120+	120+	120+	16	1.4	8.0
9	26	46	26	52	2.8	8.5	1.7	1.6	7.1	96+	96+	96+	17	3.0	5.6
10							1.2	1.8	7.8	72+	72+	72+	18	1.8	8.0
11							3.3	3.2	8.1	48+	48+	48+	18	1.2	8.8
12							6.7	4.9	9.2	24+	24+	24+	17	1.6	11.0
Average	32	67	24	57	3.5	16.0	2.8	2.9	7.6				17	2.8	8.8

[1] Tr. indicates less than 0.1 c. c.

[2] Composite of 9 samples.

The raw sewage was one of the weakest found during the survey. Leaving out the Intrenchment Creek plant at Atlanta, which, at the time of the tests, was receiving considerable storm-water dilution, only the sewage at the Brighton plant at Rochester is comparable with that at San Marcos. These two are almost identical in all the analyses made except alkalinity and chlorine. The differences in the critical constituents are less than might be expected in the daily variations of any sewage.

The septic tank, during the period covered by the analyses, was operating very efficiently. While the removal of 60 per cent of the suspended solids was exceeded at other places, this is high when the total suspended solids in the raw sewage are taken into consideration. The disposal of the tremendous accumulation of sludge produced by the activated sludge process is one of the difficulties of this process. The removal of a considerable part of it in the form of sedimentation-tank sludge by sedimentation before aeration appears to have much in its favor. It is certain that sludge disposal at this plant presents comparatively little difficulty, but whether this is due primarily to the small volume and weak character of the sewage treated and to the large capacity of the septic tank in proportion to the flow can not be definitely stated in the absence of any quantitative sludge data.

The efficiency of aeration, as judged by the reduction of ammonia nitrogen is high. During the tests the sewage was receiving 1.76 cubic feet of air per gallon. The aeration period was computed to be about three hours with an average flow of 203,000 gallons per day. The ammonia nitrogen was reduced 81 per cent as compared with 90 per cent at the south-side plant at Houston, Tex., where the volume of air used was about the same. The two main points of difference between these plants are the presettling at San Marcos and the reaeration of the sludge at Houston. The Houston plant, however, receives much more attention.

The final effluent, as judged by the above analyses, should satisfy the most exacting requirements of sewage-plant effluents. The suspended solids are practically eliminated, and the available oxygen in the form of dissolved oxygen and nitrates and nitrites is more than sufficient to satisfy the entire 5-day demand. It should be noted here, however, that, as it was impossible to do any bacteriological work on the survey, the question of the necessity for bacterial removal could not be included in the studies. The efficiencies of various plants and the character of the effluents had to be judged from the standpoint of potential physical pollution and nuisances in the receiving body of water.

Very little cost data were available. The plant was built by the San Marcos Utilities Co. with their own labor, and the final complete cost never computed. Mr. J. E. Wilson, the present manager of the company, estimated that the original cost was about $4,000. This figure is for the activated sludge device and does not include the septic tank which was part of the older disposal plant. Since the plant has been installed in 1916 there has been spent about $300 in modifications and alterations.

Maintenance costs also are not definitely known. It was estimated that one man receiving $150 per month gave about one-fourth of his time, or $450 per year, and that the cost for power was $600 per year. On the basis of these figures, treatment is costing about $14.50 per million gallons. This would be very high for a large plant, but considering the low flow, and the character of the effluent, it does not appear so excessive.

XII. Sherman, Tex.

The engineering survey of the sewage treatment plant at Sherman, Tex., was made August 23 to 24, 1920. The laboratory studies followed three months later, November 17 to 27.

Sherman, Tex., is a town of 15,000 population, located in the eastern part of the State, not far from Dallas. It is the center for a large agricultural district, and its activities are centered largely on serving this territory as a collecting and distributing point. With the exception of flour mills there are no industries of any size.

The sewerage system consists of about 23 miles of 6 to 15 inch sanitary sewers. There are no storm-water connections or roof drains, but infiltration and leakage is rather high, at some places excessive. After storms the flow in the sewers becomes so large and carries so much grit that it is necessary to by-pass the treatment plant entirely.

Local topography permits of adequate grades, the minimum for the smaller laterals being 0.5, and for the outfall sewers 0.1 per cent. Ninety to ninety-five per cent of the dead ends have flush tanks connected to the city water mains. These are operated about once every two weeks. In addition, hose flushing with a jet nozzle is done whenever stoppages occur.

There are 1,850 connections serving an estimated population of 7,500, about 50 per cent of the total of the town. In addition, there are two night-soil stations, the main one, serving 1,840 residences, located within 200 to 300 yards of the plant.

All sewage is carried to the plant, as there are no overflows on the system.

The raw sewage is typically fresh domestic. There are no industrial wastes tributary to the sewers except a laundry. While there are no industrial wastes, a large amount of night soil is discharged into the sewers. This frequently is received in an almost unbroken condition, as the main station is very near the plant. A large amount of the paper is caught on the screens, but the sewage entering the tanks is extremely concentrated at times.

No measurements of the sewage flow are made by the city. It was estimated that the flow was from one-half to three-fourths m. g. d. However, during the period covered by the laboratory tests, hourly readings were taken of the outlet weir to the final tank. The average for eight full days was one-third m. g. d. A minimum rate reading of 0.055 m. g. d. was obtained at 5 and 6 a. m., on Thanksgiving morning, and a maximum rate reading of 1.1 m. g. d. occurred at noon of a rainy day preceded by such heavy rains the night before that the plant was by-passed.

Only one-half the plant is in operation, the other half, a duplicate of the one in use, lacks only the air distribution system to put it in readiness for operation.

The sewage on entering the plant first passes through the grit chambers. These discharge through short channels into the rectangular aeration tank with filtros plate aerators. This tank is divided into three channels in series.

The effluent from the aeration tank passes to the sedimentation tank which adjoins it, separated by a common dividing wall. The outlet of the sedimentation tank is over a weir to the final effluent pipe to Town Branch, a tributary of the Red River.

Sludge drawn from the sedimentation tank is reaerated before entering the aeration tank. Excess sludge is, as a rule, allowed to accumulate in the sedimentation tank until some convenient period of high water, when it is discharged into the stream. The original plans for the plant included sludge drying beds, but these were never built.

The power plant is located in a substantial building of ample size.

There are no laboratory facilities and no analytical work is done.

The personnel at the plant consists of one man who also tends the city incinerator located at the sewage plant. From time to time a laborer is given him for special work.

No attention has been given to the grounds around the plant.

The results of the chemical analyses made at this plant are contained in the following table:

Table No. 43.—*Results of chemical analyses at the Sherman (Tex.) sewage-treatment plant.*

[Results in parts per million, except as noted.]

24-hour sample ending 8 a. m.—	Suspended matter.			Settleable solids, 2 hours, c. c. per liter.		Oxygen consumed 30′ in boiling water.		Alkalinity as $CaCO_3$ by M. O.		Ether soluble matter 24-hour comp., raw.	Chlorine as chlorides.	
	Raw.	Effluent sedimentation tank.	Raw supernatant.	Raw.	Effluent sedimentation tank.	Raw.	Effluent sedimentation tank.	Raw.	Effluent sedimentation tank.		Raw.	Effluent sedimentation tank.
Nov. 17	260	34	120	8.0	......	87	22	400	400	96	170	135
18	280	66	100	6.0	2.0	68	30	420	444	63	140	145
19	256	64	84	5.0	.9	58	28	428	440	55	125	140
20	320	144	80	7.0	15.0	79	47	410	410	78	125	140
21	280	102	64	5.5	2.5	58	29	436	432	65	130	130
22	152	57	72	2.0	.3	43	23	430	410	37	135	120
23	202	92	92	6.0	5.0	60	28	440	440	75	110	105
24	224	66	64	4.0	4.0	60	30	420	430	57	135	135
25	320	84	116	5.0	.5	62	48	440	440	91	125	122
26	301	84	101	5.6	4.0	65	48	420	420	96	125	125
27	141	52	44	1.1	.1	30	18	320	320	43	95	95
Average	234	76	85	5.0	3.4	64	32	415	416	60	129	126

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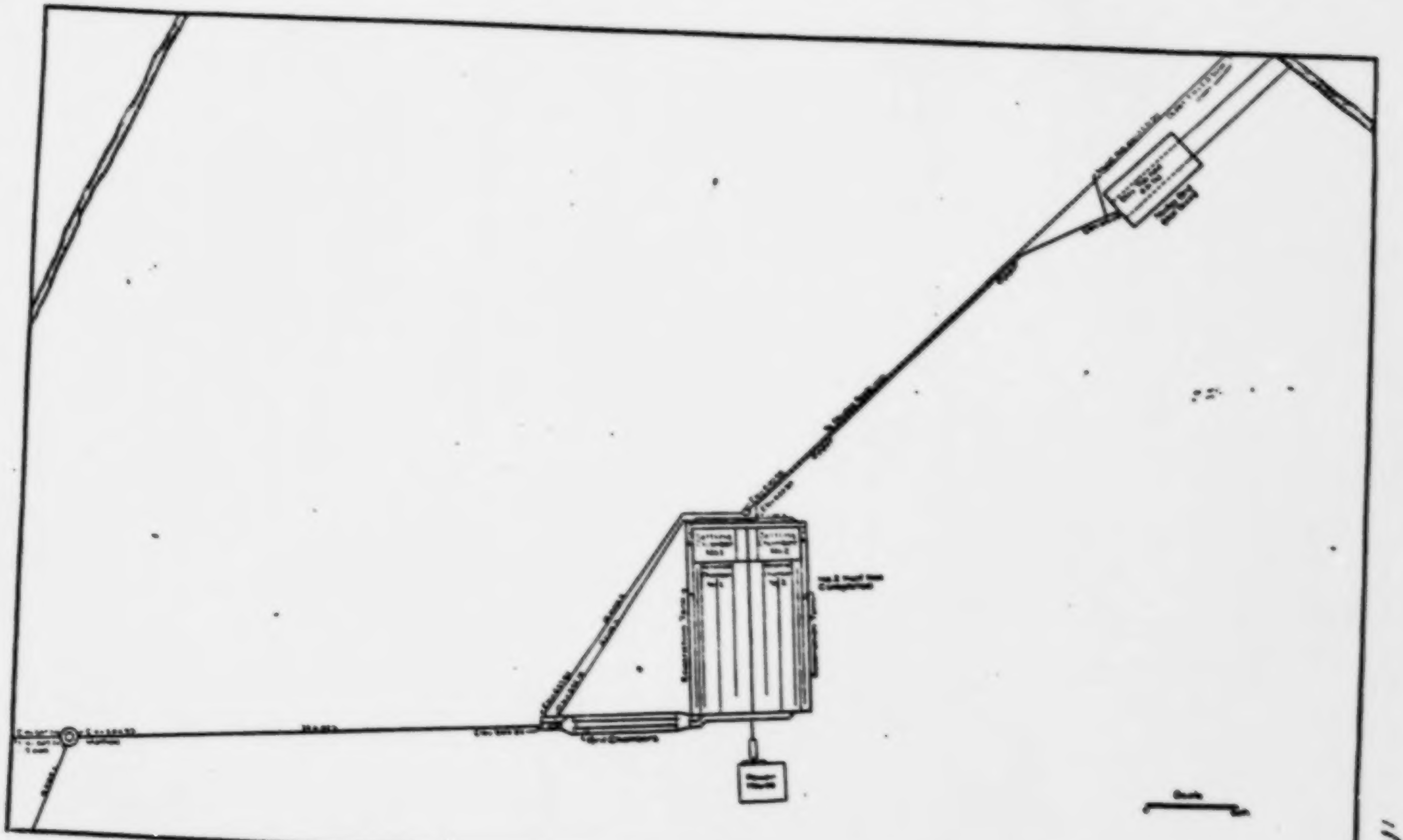

[illegible]

TABLE No. 43.—*Results of chemical analyses at the Sherman (Tex.) sewage-treatment plant*—Continued.

4-hour sample ending 8 a. m.—	Biochemical oxygen demand at 20° ± C.				Dissolved oxygen.		Hours to reduce M. B. at 20° ± C.		Nitrogen as—		
	Raw.		Effluent sedimentation tank.		Raw.	Effluent sedimentation tank.	Raw.	Effluent final sedimentation tank.	Ammonia.		Nitrates, effluent sedimentation tank.
							Per cent concentration.		Raw.	Effluent sedimentation tank.	
	1-day.	5-day.	1-day.	5-day.			10	100			
Nov. 17	49	310	6.2	22	5.2	8.4	72	120			0.8
18	66	230	10.5	43	.6	7.5	48	48	20	26	4.1
19	55	230	13.7	43	1.8	6.0	72	48	22	28	.8
20	77	230	29.0		.0	2.1	72	24	24	30	.4
21	49	175	16.5	35	.0	5.8	72	48	28	21	.3
22	38	110	7.8	23	4.7	9.1	168	72	28	28	1.5
23	60	200	12.7	41	2.4	8.9	48	48	28	18	1.5
24	77	190	18.1	44	1.5	6.6	72	24	30	22	1.0
25	44	155	22.0	66	2.2	4.7	48	24	30	28	.8
26					2.6	5.8	48	24	32	24	.9
27					4.7	7.2	24+	24+	18	22	4.5
Average	57	202	15.2	40	2.5	6.2			26	25	1.2

The raw sewage is extremely concentrated, one of the very strongest found on the survey. This was due to the dumping of relatively large quantities of night soil into the sewers, most of it within a few hundred feet of the treatment plant. With 1,850 sewer connections and 1,840 residences served by night-soil collection, the sewage should be about double an average sewage in strength. As analyzed, it is very nearly double the average of the sewages studied, and it is not believed that the analyses represent the full strength, because, as the night soil reaches the plant in masses and at irregular intervals, it is doubtful whether a proper proportion of this sewage was included in the composite samples.

While the amount of air used, 4.08 cubic feet per gallon of sewage, was greatly in excess of that used at any of the other activated sludge plants, the efficiency of the treatment as a whole was relatively low. As based on the reduction of ammonia nitrogen, aeration effected very little change. This plant was one of the few which included oxidizing devices that did not effect an appreciable reduction in the alkalinity.

The suspended solids in the final effluent is almost exactly the same as the average for all types of primary sedimentation tanks studied on this survey. The oxygen consumed is even higher. There is a greater reduction in oxygen demand, the dissolved oxygen is high, and there is some nitrification; but, on the basis of the methylene blue test, the available contained oxygen in all forms was in nearly half the samples barely sufficient to satisfy the one-day oxygen demand.

The average dilution in Town Branch, the receiving body of water, is less than one to one, and in dry weather the stream may dry up altogether. Not till the sewage reaches Red River, a distance by stream of about 30 miles, is adequate dilution assured at all times.

It is quite probable, however, that the analyses tabulated represent unusually bad conditions. A short time previous to the laboratory studies, a considerable amount of sludge had been removed, too much probably, so that the condition of that in the tanks was not normal. In addition the sludge pumps were not operating properly. It is certain that the effluent at the time of the engineering survey was much better than at the time the analyses were made. The fact that since the installation of the plant complaints and damage suits against the city have been dropped is evidence that the effluent is not normally as bad as the analyses indicate. The plant is, however, receiving but little supervision and attention, especially in view of the fact that the sewage, due to the intermittent addition of night soil, is particularly difficult to treat in a plant of this type.

Detailed costs of construction were not obtainable; only the total of $35,000 was available. This figure, of course, includes that half of the plant which is not in use.

The operating cost is not exactly known, but the following are fairly accurate estimates. The total was $3,400 per year, made up as follows:

Regular operator	$1,200
Extra labor	120
Supplies	80
Power	2,000

In addition to running the plant, the operator also tends the small city refuse incinerator which is located at the plant. This takes at least half of his time, if not more. Charging this off, the total is reduced to $2,800, or $23.33 per million gallons on the basis of an average daily flow of 330,000 gallons. The power cost is estimated on the basis of the current consumed by a 22-horsepower motor with current at 1½ cents per kilowatt hour.

CHAPTER V.

STRUCTURAL FEATURES AND EFFICIENCY OF THE TREATMENT DEVICES AND PROCESSES STUDIED DURING THE SURVEY.

RAW SEWAGE.

With the exception of cities served by strictly sanitary sewers, the total volume of sewage is seldom obtainable. Storm overflows carry off a part which is almost never measured and rarely estimated. On some separate sewers this same condition exists.

The average normal or dry weather flow is, however, the important figure for use in the design of a sewage treatment plant. Given this value the plant is designed to handle multiples of this flow, the multiple factor generally being 2 to 3, and the excess is passed around the plant without treatment.

At 13 of the plants visited it was possible to obtain actual measurements of the normal dry-weather flow. At 8 plants it was also possible to obtain fairly accurate information concerning the contributing population. These data are presented in the following table, which also shows the number of connections per capita, the gallons per capita daily of sewage, and the gramb per capita daily of oyxgen required to stabilize the sewage:

TABLE No. 44.—*Basic data pertaining to sewage.*

City.	Contributing population (thousands.)	Average dry weather flow m.g.d.	Number of connections to sewers.	Number of persons per connection.	Gallons of sewage per capita daily.	Oxygen consumed, 30' boiling.	5-day oxygen demand.	Grams of oxygen required per capita daily.	
								Basis of oxygen consumed, 30' boiling.	Basis of 5-day oxygen demand.
Alliance	20	2.63	4,900	4.1	131	28	92	18.8	45.6
Baltimore	520	55	101,000	5.2	106	42	120	17.2	45.1
Canton	70	4.44	15,700	4.5	64	61	213	14.8	51.6
Columbus	225	21.2	41,000	5.5	94	62	190	23.4	67.6
Fitchburg	38	3.35	....	....	88	65	155	21.6	51.6
Lexington	28	2.5	4,500	6.2	89	72	144	10.8	46.5
Reading	60	6.04	11,900	5.0	101	45	116	17.2	45.1
Rochester (Irondequoit)	240	33	....	....	137	29	104	20.2	53.9
Averages	....	....	....	5.1	101	....	....	17.9	51.1
Atlanta (Intrenchment)	[1] 30	[1] 5	....	....	[1] 167	33	63	[1] 22.1	[1] 39.8
Atlanta (Peachtree)	[1] 75	[1] 12	....	....	[1] 160	35	52	[1] 21.7	[1] 31.5
Houston (north side)	[1] 80	6	14,000	[1] 7.1	[1] 75	45	116	[1] 12.8	[1] 31.5
Houston (south side)	[1] 20	1.5			[1] 75	38	112	[1] 10.8	[1] 22.9
Rochester (Brighton)	[1] 8	[2] 1.02	1,215	[1] 6.6	[1] 128	34	67	[1] 11.6	[1] 31.8
San Marcos	[1] 2.5	.20	368	[1] 6.8	[1] 80	29	67	[1] 8.8	[1] 22.5
Sherman	[1] 7.5	.33	[3] 1,880	[1] 4.0	[1] 44	64	202	[1] 10.6	[1] 32.6

[1] Rough estimates.
[2] Daytime flow only.
[3] In addition there are 1,840 residences indirectly connected through night-soil disposal.

In the above table the population figures for Atlanta, Houston, Rochester (Brighton), San Marcos, and Sherman are to be regarded as rough estimates. The per capita values derived for these plants indicate a general tendency to overestimate the contributing population or to underestimate the sewage flow.

In estimating sewerage and water supply conditions in localities where population data are not available the round number of 5 persons per connection is commonly used. The average from the data obtained in this survey is 5.1.

The per capita contribution of sewage in the above table varies from 44 gallons per day at Sherman, to 167 at the Atlanta-Intrenchment plant. The average value derived from plants where accurate population data were available is 101 gallons per capita daily. This value is affected by many factors, some of which may have little connection with the normal domestic use of water. The amount of infiltration and the general character of the city, whether industrial or residential, are important elements in determining the volume of sewage. Domestic sewage is also subject to variation according to the character and density of the population and the sufficiency of the water supply, the extent to which the individual water services are metered, and other local factors.

The grams of oxygen required per capita daily to satisfy the 5-day oxygen demand of the sewage is given in the last column of Table No. 44. The average value derived is 51.1 grams per capita daily, indicating an ultimate oxygen requirement of about 75 grams of oxygen per capita daily or 2,200 pounds per capita per year. It is to be noted that this value is somewhat lower than has been previously assumed.

In the 15 plants studied, the character of the raw sewage varied within wide limits; at some places, such as Canton and Fitchburg, it was two or three times as strong as at some others such as the Brighton plant at Rochester and the plant at San Marcos. The following table summarizes the analytical data pertaining to raw sewage:

TABLE No. 45.—*Analyses of raw sewages studied during the survey.*

[Results in parts per million except as noted.]

City.	1-day oxygen demand.	5-day oxygen demand.	Oxygen consumed, 30' in boiling water.	Suspended matter.	Settleable solids, 2 hours, c. c. per liter.	Ether soluble matter.	Ammonia nitrogen.	Suspended matter in supernatant.	Chlorine as chlorides.	Dissolved oxygen.	Alkalinity as Ca CO3 by M. O.
Atlanta (Peachtree)	15	52	35	220	2.5	80	......	......	[illegible]	6.0	[illegible]
Atlanta (Intrenchment)	35	63	35	108	2.4	109	......	......	[illegible]	.0	78
Rochester (Brighton)	22	67	24	101	2.0	16	......	18	65	2.7	178
San Marcos	32	67	30	110	2.2	18	15	18	53	2.6	[illegible]
Alliance	36	92	35	132	2.0	37	......	37	47	3.0	154
Rochester (Irondequoit)	45	104	30	188	2.1	34	......	58	53	.0	175
Houston (south side)	30	113	36	226	2.0	38	16	66	101	.5	204
Houston (north side)	32	116	45	200	2.5	30	17	46	138	.2	270
Reading	62	118	45	145	2.0	25	......	57	130	......	164
Baltimore	59	130	43	150	2.9	45	......	45	[illegible]	.3	130
Lexington	55	144	37	166	2.4	56	......	14	80	.1	198
Fitchburg	78	155	66	[illegible]	2.7	63	......	55	70	.6	97
Columbus	70	190	63	[illegible]	2.1	100	......	[illegible]	113	1.7	211
Sherman	57	202	64	[illegible]	4.0	90	28	[illegible]	129	2.5	416
Canton	118	212	61	261	5.3	82	......	62	79	.5	242
Average	52	121	46	167	2.7	53	19	45	96	1.2	[illegible]

In Table No. 45, the various plants are arranged according to the magnitude of the 5-day oxygen demand, and the values presented are averages in all cases. The ammonia nitrogen determination was made only at the activated sludge plants. The table serves to illustrate the range of sewage strength studied during the survey. The 5-day oxygen demand varied from 52 at the Atlanta Peachtree Creek plant, to 213 at Canton, the oxygen consumed varied from 24 to 65, and the suspended matter from 101 to 297 at Rochester (Brighton) and Fitchburg, respectively.

The reason for the strength of the Canton sewage is not apparent. Industrial wastes have been eliminated from the sewers, and, at the time of the engineering survey, no night soil was disposed of in the sewers. This method of disposal was contemplated, however, and may have been started in the interval between the engineering survey and the laboratory studies. At Sherman the strength of the sewage is due to the relatively large amount of night soil entering the sewers. The population is about evenly divided between those contributing through sewer connections and through night-soil collection. At Atlanta heavy rains were encountered at the time of the survey; the indicated values for the strength of the raw sewage are probably much too low.

Any attempt to estimate the relative strength of the raw sewages would necessitate the weighting of the various determinations. In the absence of generally accepted standards of relative merit, the findings would be of doubtful value. If, however, we select as criteria the 5-day oxygen demand, the oxygen consumed, and the suspended matter, it is evident that these three determinations vary concurrently. In this sense the raw sewages presented in Table No. 45 may be said to be arranged in the order of their relative strengths, precedence being given to the 5-day oxygen demand value. The relative position of several sewages which are of nearly equal strength would be altered if the oxygen consumed or the suspended matter were to be selected as a basis of reference; the general sequence, however, would not be materially affected.

The average values given are simple averages, no account being taken of the number of plants falling into each group of possible sewage strengths. They are accordingly valid only if it is assumed that the plants selected for study were truly representative of the general distribution, a circumstance which can not very readily be substantiated. The values, however, appear to approximate very closely to the figures generally assumed as representing the strength of the average American sewage.

It is probable that few municipal sewages are weaker than some of those studied during the survey. In the absence of industrial wastes, the strongest sewages are also well represented. Where industrial wastes form an appreciable part of the sewage, as at Gloversville, N. Y., the strength may be considerably greater than the above table would indicate. Average analyses from other sources are given in Table 46. The values are taken from a table in the 1914 report of the Cleveland sewage-testing station.

TABLE No. 46.—*Analyses of raw sewages from other sources.*

[Results in parts per million except as noted.]

City.	Oxygen consumed, 30′ in boiling water.	Suspended matter.	Chlorine as chlorides.	Ammonia nitrogen.
Chicago	38	141	40	8.5
Waterbury	46	105	48	7.8
Cleveland	50	252	246	12.0
Philadelphia	75	180	30	4.0
Akron	86	238	917	6.6
Columbus	93	215	65	11.0
Gloversville	95	406	158	12.0

Grit chambers.—At plants where sewerage from combined sewerage systems or from certain types of industries is treated, it is good practice to provide means for the removal of heavy inorganic matter, such as sand, gravel, etc., before the sewage is admitted to sedimentation or aeration tanks for the removal of organic solids. If carried over into these tanks, they will cause considerable trouble. In sedimentation tanks, sludge containing much grit is difficult and at times impossible to remove by normal means, and the heavy solids settle to the bottom and reduce the sludge storage capacity of the tank.

In activated sludge plants, grit carried over to the aeration tanks will either settle and lie over the aerators, reducing the efficiency of this tank, or will necessitate the use of an extravagantly large amount of air to keep it in suspension.

The grit chamber, or detritus tank, is the device commonly used to remove these inorganic solids. In principle, they are designed to pass the sewage at a rate sufficiently low for the deposition of the heavier inorganic solids, but not low enough for the deposition of any large amount of the organic putrescible solids. At Cleveland, Ohio,[1] "It was found that grit which on the average contained more than 15 per cent of volatile matter would be offensive." This per cent of allowable volatile matter will vary with different sewages, but it should be maintained low enough to prevent nuisances when used as a fill.

A velocity of 1 foot per second through the grit chambers and detentions from one-half to one minute are frequently used as nominal figures. At the Cleveland tests, already quoted, it was found that "in general velocities of less than 25 feet per minute do not produce the proper grade of grit and in 25-foot chambers velocities of 60 feet usually carried by some material which should have been deposited." Based on the tests, the grit chambers recommended for this city called for detention periods of 50 seconds, with velocities from 30 to 60 feet per minute.

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[1] Report on tests at sewage testing station. Cleveland, Ohio, 1914.

Metcalf and Eddy state:[3]

> The Rochester experiments with a model grit chamber confirm the general deduction from available experimental information and service experience, that a mean velocity of about 1 foot per second is about right, unless it is necessary to remove very fine and light material, in which case it may be desirable to reduce the velocity and run the risk of some offensive organic matter settling with the grit.

In the design of the grit chambers provision should be made for the storage of deposited grit. This storage is, of course, dependent on the amount of grit deposited and the frequency of cleaning. It is impossible to give any general figure for the amount of grit removed. The character of the sewage, the geology and topography of the vicinity, condition of streets, tightness of sewers, industries contributing, and other local conditions are all important factors. Data from many operating plants are misleading as it is probable that comparatively few grit chambers are operated at attainable efficiency. Most grit chambers are designed for a definite period of storage between cleanings with an estimated deposition, and errors in these estimates are corrected in operation by changing the period between cleaning.

At most of the plants the grit chambers are cleaned by hand with shovels. At the very large plants, however, there are frequently installed grab buckets, bucket conveyors, or removable containers, some of which are used without interfering with the normal operation of the chamber.

All but two or three of the plants surveyed had some form of grit chamber, though at several they are, or have been remodeled, to serve merely as influent channels. Others because of infrequent cleaning are acting as grit chambers during only a part of the time.

There is so little uniformity in design and operation of this device at different plants that no attempt is made to tabulate structural details and operation data. For such detail of design and arrangement, reference is made to descriptions of the plants in Appendix I.

No analytical work was done to demonstrate the effect of grit-chamber treatment. The only service rendered by grit chambers is the removal of inorganic solids, and it has been shown that this removal is not of such a nature or of sufficient amount to materially affect the suspended matter content of the raw sewage.

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[3] American Sewerage Practice, Metcalf and Eddy, Vol. III, p. 295.

SEDIMENTATION TANKS.

Plain sedimentation tanks.—The very early sewage-treatment tanks were operated on the plain sedimentation principle, their one and only function being to remove the suspended solids from the sewage, which when removed were transferred to other tanks for digestion or disposed of as fresh sludge. This removal of the sludge was made at frequent intervals, before bacterial decomposition had progressed far enough to produce sufficient gas formation to lift the sludge to the surface of the sewage in the tank. These tanks had, as a rule, flat bottoms and were cleaned by draining off the supernatant sewage, removing the sludge, and flushing out the tank.

Detention periods in this type of tank range from half an hour to six hours, longer periods being considered detrimental, especially where the effluent is to be further treated, as decomposition or septization becomes well established in the sewage if retained too long in a tank. Theoretically, if a sewage contains dissolved oxygen when entering the tank, the effluent will also contain it.

This type of tank was studied only at Alliance, Ohio. Reference is made to the description and discussion of this plant for details connected with its design and operation. No analyses were made of the effluent of this type alone. At Alliance the plain sedimentation tanks were operated in parallel with Imhoff tanks, and the sample of tank effluent analyzed was the combined effluent from both types.

Septic tanks.—This type illustrates the step in the development of sedimentation tanks following the plain sedimentation tank. The most distinctive difference between the two types consists in the operation, whereby the sludge, instead of being removed at frequent intervals, is allowed to remain in the tank and undergo decomposition.

In the operation of septic tanks, the sludge settling to the bottom is attacked by anaerobic bacteria which liquefy some of the solids. This is accompanied by the formation of gas which, entrained in the sludge, lifts it to the surface where it lies as a heavy scum until the gas is liberated. Then some of this scum may resettle to the bottom. There is, therefore, sludge continually passing up and down through the sewage passing through the tank, some of it washing away with the effluent.

As the bacterial action in the sludge is anaerobic, it was at first considered essential that the tank be protected by an airtight cover. This is no longer considered necessary, as it is known that the oxygen taken from the air in contact with the sewage at the surface of the tank is used up before reaching the bacterial workhouse at the bottom of the tank.

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FIG. 25.—GRIT CHAMBERS AT CANTON, OHIO.

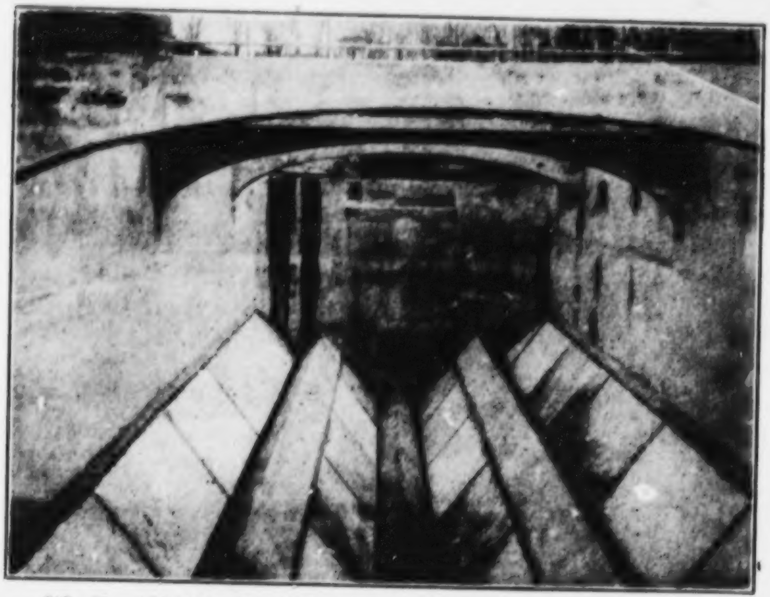

FIG. 26.—INTERIOR OF IMHOFF TANK AT THE BRIGHTON PLANT AT ROCHESTER, N. Y.

It was claimed at first that liquefaction of the sludge amounted to 50 per cent of the solids settled in the tanks, and even now it is frequently claimed, for commercial purposes, that this figure is correct or even low, manufacturers of some devices of this type even claiming complete liquefaction. It is now felt, however, that this liquefaction is not more than 30 per cent, and probably less. The apparent larger figure of 50 per cent was due to the fact that every now and then a large amount of sludge is taken up by the sewage as it flows through the tank while the sludge is rising or falling through the sewage, and this sludge is carried out with the effluent. This phenomenon is known as "unloading."

The effluents from septic tanks may be clear and colorless; may have a slight opalescent color due to the presence of hydrogen sulphide, a product of the decomposition of the sludge; or, at times of unloading, may contain fine black sludge in sufficient quantities to give the entire effluent a very dark or black color.

Early in its development the septic tank principle was patented. There resulted from this considerable litigation.

> The effect of this long litigation was to prevent in the United States the development of such favorable opinion of septic tanks as existed in England. This was inevitable when conservative engineers hesitated to involve municipalities in suits in the Federal courts and the engineers who were not so conservative were frequently restrained from risking such suits by the legal advisers of the cities. A large number of tanks were probably built under the name of septic tanks from the plans of persons without adequate knowledge of the principles of sewage disposal, and the failure of these to accomplish the anticipated results and the nuisance caused by some of the worst of them did not help raise the status of this method of treatment.[3]

The development of the Imhoff tank, discussed elsewhere, offered a relief from the litigation over the septic-tank process, and this type rapidly replaced the septic tank. The Imhoff tank also was patented, but the attitude of the inventor and promoters was such as to win the approval instead of the enmity of American engineers.

With the exception of very small installations the septic tank is very seldom found in this country, though there are some installations made previous to the advent of the Imhoff tank. Many of such installations have been converted into Imhoff tanks, as at Columbus, Ohio, and at others, as Reading, Pa., the officials in charge of the plants are planning such conversion.

Septic tanks were studied on this survey at but two places, Reading, Pa., and San Marcos, Tex. The tanks at these two plants are of such widely different capacity and of such different design that no direct comparison is possible. Reference is made to the discussions and descriptions of these plants in the body of this report and in Appendix I.

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[3] American Sewerage Practice. Metcalf and Eddy, Vol. III, p. 17.

Hydrolytic tanks.—This type of tank was studied on the survey at Baltimore, Md. These tanks were operated as plain sedimentation tanks, except that the period between cleanings was sufficient for the formation of a heavy scum and for initial digestion of sludge. Before, however, septic action had progressed sufficiently to materially injure the effluent, they were completely cleaned, the sludge being pumped to separate tanks for digestion.

A discussion and a complete description of these tanks is given under the Baltimore survey and in Appendix I.

Imhoff tanks.—The Imhoff tank is, by far, the predominating type of primary sedimentation tank used in this country. With the exception of the activated sludge plants, all but one of the plants surveyed, Reading, Pa., use these tanks either exclusively or in combination with other types. The city engineer of Reading, moreover, is anxious to convert his septic tank into several Imhoff tanks. Two plants, those at Alliance, Ohio, and Baltimore, Md., use septic and hydrolytic tanks, respectively, in parallel with the Imhoff tanks.

The Imhoff tank is primarily a combination of a plain sedimentation tank and a sludge digestion tank. When these two tanks are operated as separate units, the settled solids, or sludge, are transferred from the sedimentation tank to the sludge tank periodically, before septic action and fermentation has developed to any extent. With the Imhoff tanks this transfer is a continuous operation. The sedimentation tank is built in the upper part of the tank with a bottom opening or slot through which the solids drop from the sedimentation compartment into the sludge compartment. This slot is built so that one side overlaps the other, thus forming a trap to prevent the solids, when buoyed up by gasses of decomposition, from reentering the sedimentation compartment. They are instead diverted to sections of the tank, the gas vents, which are separate from the sedimentation compartment.

It is believed that the various types of Imhoff tanks are well represented at the plants surveyed. The radial and longitudinal flow type, as well as the shallow and deep types were studied, and most, if not all, the different arrangements of gas vents were included.

In the following table an effort has been made to tabulate the various salient features of Imhoff tank construction as found at the plants surveyed.

TABLE No. 47.—*Structural features of Imhoff tanks studied.*

Plant.	Number of tanks.	Tank as a whole.							
		Shape.	Length (feet).	Width (feet).	Overall depth (feet).	Population served (thousands).	Volume sewage treated (m.g.d.).		Reversible flow.
							Average.	Maximum.	
Alliance	2	Rectangular	35.2	60.6	28.5	5.25	0.635	1.12	Yes.
Atlanta (Intrenchment)	21	([1])	31.8	25.0	26.0	[2]4.20	[3].714	[3].856	Yes.
Atlanta (Peachtree)	30		31.8	25.0	26.0	[2]7.50	[3]1.2	[3]1.2	Yes.
Baltimore	28	Circular	30 feet diameter		25.8	3–4	.265	....	No.
Canton	6	Rectangular	89.0	24.0	22.1	10.0	.74	.94	Yes.
Columbus (Battery A)	8	do	140.7	25.6	27.1	10.2	.96		Yes.
Columbus (Battery B)	8	do	128.2	25.6	27.1				Yes.
Columbus (Battery C)	6	do	117.7	26.6	27.1			....	Yes.
Fitchburg	5	do	90.0	30.0	25.9	9.25	.76	[5]2–2½	Yes.
Lexington	4	do	68.0	33.0	28.7	7.00	[4].60	[5]1.25	Yes.
Rochester (Brighton)	1	([6])	62.5	30.0	37.0	8.00	1.07	1.86	Yes.
Rochester (Irondequoit)	10	Rectangular	110.0	35.0	40.0	24.00	3.24	5.91	Yes.

Plant.	Flow chamber.								
	Number per tank.	Shape.	Length (feet).	Width (feet).	Depth to spring line (feet).	Depth to apex of slot (feet).	Freeboard (feet).	Sedimentation area exclusive of gas vents (sq. ft.).	Cross section at center (sq. ft.).
Alliance	4	Rectangular	35.2	12.2	17.2	14.1	1.75	449	169
Atlanta (Intrenchment)	1	do	31.8	17.8	7.2	14.8	1.25	603	179
Atlanta (Peachtree)	1	do	31.8	20.0	7.2	14.8	1.25	622	179
Baltimore	1	Circular	30 feet diameter		3.5	13.5	.83	973	....
Canton	2	Rectangular	89.0	10.0	7.5	13.4	1.5	890	89
Columbus (Battery A)	2	do	140.7	11.8	8.0	15.7	1.9	1,750	140
Columbus (Battery B)	2	do	128.2					1,550	140
Columbus (Battery C)	2	do	117.7					1,550	140
Fitchburg	1	do	90.0	26.0	9.1	15.9	1.5	2,185	232
Lexington	1	do	68.0	33.0	7.8	16.0	2.0	2,060	255
Rochester (Brighton)	1	([6])	60.0	24.0	11.0	21.0	2.0	1,440	340
Rochester (Irondequoit)	2	Rectangular	110.0	10.0	10.5	18.5	5.5	1,155	183

Plant.	Flow chamber.								
	Ratio width to length, 1 to —.	Free area gas vents per chamber (sq. ft.).	Gas area of sedimentation area (per cent).	Capacity (thousand gallons).	Volume sewage treated (m.g.d.).		Detention on total disp. hours.	Velocity per minute (feet).	Slope of bottom 1 to —.
					Average.	Maximum.			
Alliance	2.9	46.3	10.3	30.9	0.164	0.280	4.7	0.12	1.1
Atlanta (Intrenchment)	1.8	62.5	10.4	42.7	.714	.856	[2]4.2	.37	1.5
Atlanta (Peachtree)	1.6	43.7	7.0	43.5	[3]1.2	[3]1.2	[2]2.6	.61	1.5
Baltimore	....	22.3	2.3	63.9	.365	....	3.8	.06	1.25
Canton	8.9	115.0	12.9	60.0	.37	.47	3.9	.38	1.2
Columbus (Battery A)	12.4	163.0	9.3	118	.48	....	5.5	.85	1.3
Columbus (Battery B)	10.7	140.0	9.0	108.0	.48	....	5.4	.78	1.3
Columbus (Battery C)	10.8	142.0	9.1	109.0	.48	....	5.4	.79	1.3
Fitchburg	3.5	438.0	20.0	185.0	.76	....	5.8	.26	1.5
Lexington	2.1	156.0	7.5	155.0	[4].60	....	6.2	.18	1.25
Rochester (Brighton)	2.5	162.0	11.2	153.0	1.07	1.86	3.4	.29	1.33
Rochester (Irondequoit)	11.0	432.0	28.0	69.4	1.62	2.98	1.0	1.8	1.25

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[1] Circular with flow chamber rectangular and overlapping the circular sludge chamber.
[2] Three tanks in series.
[3] Rate, not a 24-hour flow.
[4] Estimated.
[5] Maximum storm rate.
[6] Parallel sides, circular ends.

TABLE No. 47.—*Structural features of Imhoff tanks studied*—Continued.

Plant.	Flow chamber.							Digestion chamber.	
	Clearance of slot (inches).	Overlap of slot (inches).	Scum-boards.	Baffles.	Type inlet.	Type outlet.	Volume per capita served (gallons).	Shape.	Length, (feet).
Alliance	7	9	Inlet and outlet.	No.	Weir	Weir	23.5	Rectangular	22.9
Atlanta (Intrenchment).	10	7		1	do	do	[1] 29.8	Circular	([2])
Atlanta (Peachtree).	10	7		1	do	do	[1] 17.4	do	([2])
Baltimore	8	8	Outlet	No.	do	do	16-21	do	([3])
Canton	6	3	Inlet	Yes.	Free	do	12.0	Rectangular	80.0
Columbus (Battery A).	8	10	Inlet and outlet.	No.	Weir	do	11.5	do	135.0
Columbus (Battery B).	8	10	do	No.	do	do	10.5	do	116.0
Columbus (Battery C.).	8	10	do	No.	do	do	10.6	do	117.7
Fitchburg	6	3	do	No.	Sluice gates.	do	20.0	do	90.0
Lexington	9	10	do	(?)	Weir	do	22.1	do	55.0
Rochester (Brighton).	7	12	do	No.	do	do	19.1	([4])	62.5
Rochester (Irondequoit).	9	11	do	No.	do	do	5.8	Rectangular	110.0

Plant.	Digestion chamber.								
	Width (feet).	Depth-slot overlap to bottom (feet).	Hoppers.						Capacity to overlap of slots (cu. ft.).
			Number.	Shape.	Least slope of bottom — to 1.	Length (feet).	Width (feet).	Depth (feet).	
Alliance	60.50	13	3	Rectangular	2.1	22.9	15.6	5.0	10,800
Atlanta (Intrenchment).	([2])	10.25	1	Circular	2.0	25 feet diameter		6.25	3,040
Atlanta (Peachtree)	([2])	10.25	1	do	2.0	25 feet diameter		6.25	3,040
Baltimore	([3])	12.25	1	do	2.0	23 feet diameter		5.3	3,600
Canton	14.0	7.50	6	Square	2.5	14.0	14.0	2.75	7,900
Columbus (Battery A)	14.8	9.5	7	Rectangular	2.0	18.6	14.8	4.3	13,500
Columbus (Battery B)	14.8	9.5	6	do	2.0	18.6	14.8	4.3	11,700
Columbus (Battery C)	14.8	9.8	6	do	2.0	18.6	14.8	4.3	11,800
Fitchburg	20.0	10.0	3	Square	2.0	30.0	20.0	7.5	13,000
Lexington	20.0	11.08	2	Rectangular	3.0	27.0	20.0	4.5	7,700
Rochester (Brighton)	30.0	14.33	2	½ rectangular, ½ circular.	2.5	30.0	30.0	6.0	17,900
Rochester (Irondequoit).	35.0	21.25	3	Nearly square	2.0	35.75	35.0	8.0	50,500

Plant.	Digestion chamber.						
	Size of sludge pipe (inches).	Head over sludge pipe (feet).	Water lines.		Baffles.	Volume per capita served (cu. ft.).	Volume per m. g. d. treated (cu. ft.).	Cubic feet per p. p. m. influent per m. g. d.
			Around hopper.	Mouth of outlet.				
Alliance	8	4	Yes	Yes	Yes	1.0	8,000	58
Atlanta (Intrenchment)	8	6½	Yes	Yes	No	[1] 2.12	[1] 12,800	121
Atlanta (Peachtree)	8	5	Yes	Yes	No	[1] 1.28	[1] 7,600	33
Baltimore	8	5	No	No	No	1.2-.9	10,700	67
Canton	8	3-4½	Yes	Yes	Yes	.78	10,700	41
Columbus (Battery A)	8	4	No	No	Yes	1.31	14,100	66
Columbus (Battery B)	8	4	No	No	Yes	1.14	12,200	39
Columbus (Battery C)	8	4	No	No	Yes	1.15	12,300	88
Fitchburg	8	Airlift.	No	No	No	1.41	17,000	57
Lexington	8	4½	Yes	Yes	Yes	1.1	11,600	70
Rochester (Brighton)	8	5	Yes	Yes	Yes	2.24	16,700	153
Rochester (Irondequoit)	8	5	No	No	Yes	2.48	18,400	99

[1] Three tanks in series.

[2] 25 feet diameter.

[3] 23 feet diameter.

[4] Parallel sides, circular ends.

While at four of the plants, Baltimore, Rochester, Brighton, and two at Atlanta, the circular type of construction was found; at only one, Baltimore, is the flow radial. At the other three plants the flow chambers are all of the type found in the rectangular tanks with the sewage flowing across the tank. In these plants the circular construction applies only to the gas vents and sludge chambers. The Baltimore tanks are the only ones in which the direction of flow can not be reversed.

A discussion of many of the details of the above table would be of comparatively little value. There are some points, however, which should be mentioned to explain parts of the table, and others which are deserving of special attention. For the Alliance plant, the table gives the width of the tanks as a whole as nearly twice the length. This is due to the fact that the width includes four flow chambers. The ratio of width to length for both the Atlanta plants is that for each individual tank, whereas in operation three tanks must always be run in series, which is equivalent to multiplying the stated ratio by 3. This applies also to the Canton plant, though here it is possible to operate the tanks in parallel.

In a general way the table is of particular value in showing the wide variations in the design factors of Imhoff tanks. Lengths vary from 35 feet at Alliance to 141 feet at Columbus. Considerable importance at some of the plants was attached to the depth factor. The effective depth, the total depth less the freeboard, varies from about 21 feet at Canton to nearly 35 feet at both the Rochester plants. At these latter plants the depth factor is credited with some of the favorable operating conditions obtained, such as the absence of foaming. While analytical results, as given later, afford a means of comparison of the efficiencies of different tanks, it is not believed possible to credit favorable differences to any one factor of design or operation, inasmuch as other factors of equal importance introduce differences that can not be eliminated nor compensated for. The character of the raw sewage, the detention period, and velocity of flow are all of sufficient weight to prevent any comparisons.

The per cent of the gas area to the sedimentation area has received considerable attention in connection with the control of foaming. The tendency has been to make this area about 10 per cent of the surface area of the tank or 11 to 12 per cent of the sedimentation area as used in the above table. This percentage is approximated by 7 of the 12 plants listed, and two others are only 3 to 4 per cent below this figure. The remaining three, however, are radically different. At Fitchburg the percentage is twice and at the Irondequoit plant at Rochester three times the average of the first nine mentioned, while at Baltimore it is only about one-quarter of this average.

At Fitchburg but little trouble has been encountered by foaming. Mr. H. B. Allen, chemist in charge, stated that foaming was not considered a problem at his plant. It persists for only two to four days and is readily stopped or controlled by drawing sludge and pushing down scum with a paddle. Experience at this plant has been that a good heavy sludge does not foam, and for this reason he does not use a stream of water to break up scum in a foaming vent in order not to dilute further a light sludge.

At Rochester, Irondequoit plant, the tanks have never foamed except one tank, which on one occasion foamed for 7 to 10 days. The lack of foaming was attributed by Mr. N. A. Brown, special assistant engineer, to the depth of the tanks, the character of the sewage, a dilute well broken up domestic sewage, and the removal by Riensch-Wurl screens of floating vegetable refuse.

At Baltimore during the early stages of operation considerable trouble was experienced with foaming and excessive scum formation, scum forming even in the sedimentation chamber to depths of, at times, 2 feet. The tanks were taken out of service and slightly modified to correct certain hydraulic factors which interfered with operation. They have since been started again and very little trouble has been caused by foaming which when it did occur, was easily controlled by the use of a hose for a few minutes.[4]

Mr. C. C. Hommon, chemist in charge of the Atlanta plants, was of the opinion that gas vent areas are generally designed too large, preferring the tanks at the Peachtree Creek plant with 7 per cent gas areas to those at the Intrenchment Creek plant with 10.4 per cent. Moreover, some of the vents at the Peachtree plant are capped with a metal gas collector and vented through a one-half-inch gas line. These have never given trouble.

All Imhoff plants visited had experienced foaming to some extent. The tanks at Alliance foam at irregular intervals throughout the year. At this plant fresh sludge from plain sedimentation tanks is pumped into the Imhoff tanks weekly. At Canton, also, foaming occurs off and on throughout the year, though more actively in the summer. On several occasions when attempting to relieve foaming by withdrawing sludge, it was found that only sewage flowed from the sludge pipe, and it was necessary to break up and push down the sludge in the gas vents before any could be removed. The tanks at Lexington foamed considerably during the first year of operation, but in the past two years, while foaming occasionally, have not caused any serious trouble.

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[4] Nine Years Operation of Baltimore Sewage Works, T. C. Schaetzle, Engineering News-Record, vol. 87, pp. 50–54, 97–101.

Mr. J. F. Skinner stated that the tank at the Brighton plant at Rochester had never foamed. He attributes this to the dilute sewage treated, the method of starting operation, which consisted in first filling the tank with water and gradually adding sewage, the seeding of the tank with well digested Imhoff sludge, and the fact that operation was started in the early spring, March.

At Columbus, Mr. C. D. McGuire stated that the Imhoff tanks started foaming each spring about four weeks after they were put in operation. As the plant is not operated during the winter the tanks are idle from about December to April. In 1920 one set of tanks, which was not put in operation in the spring, started foaming about June 1, with sludge from the previous year, and this foaming continued for three to four weeks. In line with Allen's statement at Fitchburg that his heavy sludge did not foam, McGuire has noted that at Columbus foaming almost always starts in the middle hoppers and that the inlet hoppers are the last to foam.

It was practically the unanimous opinion of the operators of the plants visited that permanent relief from foaming could be obtained only by an adequate removal of sludge. At some plants a stream of water or other mechanical agitation is used for temporary relief to control the tanks till sludge beds are available to receive sludge.

With the exception of the Irondequoit plant at Rochester, no tanks give a theoretical detention period, figured on the total displacement of the flow chamber, under three hours, and several give periods of well over four or five. At several plants efforts have been made to determine by dye tests the actual detention period, but these tests have not been sufficiently successful for use as a reliable basis of computation.

The Irondequoit plant at Rochester stands by itself in the above table with a detention period of only one hour. At this plant the tanks are preceded by fine screens, and the dilution in Lake Ontario available for the tank effluent is so large that the extent of purification required of the plant consists in the removal of solids capable of creating visible nuisances on the surface or the shore of the lake.

The average clearance of the slot at the bottom of the flow chamber is 8 inches. One-third of the plants visited had this clearance, one-third were within 1 inch of this figure and one-third within 2 inches.

The overlap distance of the slot while varying within greater limits, 3 to 12 inches, is in all except three plants within a much narrower range, 7 to 10 inches.

Probably the most important factor in the design of the digestion chamber is the volume to be allowed per capita contributing. It is essential to provide sufficient volume to insure a thorough digestion period. Necessary capacity beyond this point is dependent upon the sludge-bed area available and climatic conditions. For a plant with adequate sludge-bed area and weather conditions permitting of continuous use throughout the year, a storage over a liberal digestion period is sufficient. Where, however, it is necessary to hold sludge in the tanks over the winter months, provision must be made for this additional storage.

With the character of the raw sewage treated at different plants varying within wide limits it is impossible to compare the sludge storage capacity in more than a very general way. In the last column of the table, a comparison is made on an empirical basis, taking into consideration the capacity of the digestion chamber, the average daily volume of sewage contributing sludge, and the average suspended matter content of the influent as determined by analyses made during the survey. The figure given represents the cubic feet of storage per parts per million of suspended matter per million gallons daily.

The factors given by this method reverse in several instances the relative figures given for the volume per capita served. This reversal is well illustrated by the Fitchburg and Lexington plants. Considering the differences in the composition of sewages and the fact that the computations are made on the basis of 1920 operating conditions, five to seven years after the plants were constructed, it seems rather surprising that so many plants should have factors within such relatively narrow limits. Moreover, some of the plants furthest from the most common average are subject to possible correction. It is not believed that the suspended matter results of 106 and 226 parts per million obtained in the sewages at the Atlanta Intrenchment Creek and Peachtree Creek plants, during the period analyses were made, were representative of normal condition. In the case of the Brighton plant at Rochester the tank was designed for future growth and allows for a much higher volume of flow than that actually passing through in 1920. The two Rochester plants were, moreover, intentionally designed with exceptionally large digestion chambers.

The Canton plant represents the other extreme among the plants visited, but the storage here has always been sufficient to produce well digested sludge, and the lack of capacity in the tanks has been offset by the use of large areas for the disposal of sludge. Additional tank capacity will probably be provided in the near future.

It was noted that at plants where sludge disposal was one of the acute problems the operators spoke more of inadequate sludge-bed facilities than of inadequate sludge capacity in the tanks.

The following table contains the average of analyses of the influent and effluent of the Imhoff tanks studied, together with the per cent removal effected by the tanks. The methylene blue stability results are not included as it is difficult to properly average these over short periods. Chlorine as chlorides is also omitted as there is no change effected in this constituent by tank treatment.

TABLE No. 48.—*Average analyses of influent and effluent of Imhoff tanks studied.*

[Results in parts per million, except as noted.]

Plant.	Suspended matter.			Settleable solids, 2 hours c. c. per liter.[1]			Oxygen cons. 30' in boiling water.		
	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.
Alliance[2]	152	69	55	2.0	Tr.	100—	32	25	22
Atlanta (Intrenchment)	106	67	37	2.4	0.6	75	35	21	40
Atlanta (Peachtree)	226	68	70	2.5	.2	92	35	18	49
Canton	261	93	64	5.3	.3	94	41	28	32
Columbus	207	79	62	3.1	Tr.	100—	65	46	29
Fitchburg	297	63	79	2.7	Tr.	100—	65	37	43
Lexington	166	67	60	2.4	Tr.	100—	32	22	31
Rochester (Brighton)	101	40	60	2.0	Tr.	100—	24	15	38
Rochester (Irondequoit)[3]	198	119	40	2.3	.7	70	44	35	20

Plant.	Alkalinity as CaCO₃ by M. O.			Biochemical oxygen demand at 20° ± C.					
				1 day.			5 days.		
	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.
Alliance[2]	184	194	−5.4	36	29	19	93	69	26
Atlanta (Intrenchment)	78	82	−5.1	25	11.2	55	61	23	62
Atlanta (Peachtree)	68	69	−1.5	15	8.5	43	53	20	62
Canton	242	242	−0	116	90	22	213	129	39
Columbus	211	219	−3.8	80	61	24	190	134	29
Fitchburg	97	99	−2.1	76	49	36	156	96	38
Lexington	196	194	1.0	65	37	43	144	87	40
Rochester (Brighton)	178	188	−5.6	22	11	50	67	38	43
Rochester (Irondequoit)[3]	175	190	−8.6	42	30	29	100	74	26

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[1] Tr. indicates less than 0.1 c. c.

[2] The tank effluent analyzed included effluents from plain sedimentation tanks operated in parallel with the Imhoff tanks.

[3] Influent is raw sewage after passing Riensch-Wurl screens.

The main function of any sewage tank is the removal of suspended matter. With the exception of Alliance where the samples analyzed were 50 per cent effluent from plain sedimentation tanks, and of the Intrenchment Creek plant at Atlanta where operating conditions were probably affected by abnormal weather conditions, and of the Irondequoit plant at Rochester where the detention is abnormally low and where the sewage was passed through Riensch-Wurl screens before entering the tanks, all tanks effected a removal of suspended matter of 60 per cent or over. The exceptionally good work of the tanks at Fitchburg is probably due to some extent to the amount of grit carried by the sewage. This naturally settles out readily and, it might be added, can cause considerable trouble in the tanks as experience at Fitchburg has demonstrated. On the basis of settleable solids only two plants gave efficiencies of less than 90 per cent.

A comparison of the reduction of the permanganate oxygen consumed with that of the 5-day oxygen demand is interesting in that the percentage of reduction of 5-day demand is at 7 out of the 9 plants, greater than that of oxygen consumed. It has been held that the removal of suspended matter affected the oxygen demand to a much less degree than the oxygen consumed. This, however, is not borne out by the above table.

Speaking generally, of all the Imhoff tank installations studied, it can well be said that they satisfactorily accomplished their purpose. At all the plants where they constitute the preliminary treatment for filters, the effluents are properly prepared for this secondary treatment, and in the one plant, the Irondequoit plant at Rochester, where they constitute final treatment, the effluent produced is capable of disposal without nuisance in Lake Ontario. At this plant, however, the detention period is too short and velocity of flow through the tanks is too great to effect removal of the lighter suspended matter.

Table No. 48, taken with Table No. 47, suggests a number of points where comparison can be made between various factors of design and efficiency. In a broad way, however, such a comparison raises a question as to the value of refinement of minor features of design in improving the character of the tank effluent. The two tables show that in spite of great variations in design factors and in the character of the raw sewage, the tanks produce effluents of a fairly standard quality so far as the design or operation of subsequent treatment devices is concerned.

Secondary sedimentation tanks.—Under the discussion of trickling filters, mention is made of unloading periods during which solids accumulated and worked over in the beds break loose and are carried out with the effluent. To prevent these solids from reaching the receiving body of water it is common practice to install sedimentation tanks following the filters.

Such tanks are in operation at Baltimore, Md., Fitchburg, Mass., Lexington, Ky., Reading, Pa., and the Brighton plant at Rochester, N. Y. They were also built at Columbus, Ohio, but in recent years have not been used, the filter effluent being by-passed around them.

At Fitchburg they are circular, of the deep, vertical flow, Dortmund type, but at all other places they are the rectangular, shallow, horizontal flow type. The following table contains some of the structural features of these tanks at the plants surveyed.

TABLE NO. 49.—*Structural features of secondary sedimentation tanks studied.*

	Baltimore, Md.	Columbus, Ohio.[1]	Fitchburg, Mass.	Lexington, Ky.	Reading, Pa.[2]	Rochester (N. Y.) Brighton plant.
Number of tanks	2	2	4	2	4	2
Length (feet)	272	240-340	[3] 30	221	96	115
Width (feet)	290	307	[3] 30	11	100-110	30
Average depth (feet)	10-12	4-6	24	5.7	3-5	2-4
Tank capacity each tank (thousand gallons)	5,700	[4] 3,400	[5] 57	[5] 55	300	75
Sedimentation area (sq. ft.):						
Total each tank	76,190	89,000	640	2,450	10,000	3,450
Per m. g. treated	2,764	8,900	700	2,000	6,670	6,270
Per acre filters	[6] 5,077	17,900	1,280	2,450	10,000	6,900

[1] These basins not operated.
[2] The four tanks are slightly different. All fall within dimensions given.
[3] Diameter.
[4] Approximately for two basins averaged.
[5] Exclusive of sludge hopper.
[6] Figured for total filter installation, though all filters are never in use at any one time.

The unit quantities of sedimentation area available per m. g. treated are computed on actual operation data and not on the designed capacities of the filters. Thus at Baltimore the average filter rate, if all filters were operated, was about 1.8 m. g. d., while at the Brighton plant at Rochester it was 1.1.

Comparison of the survey analyses of the effluents of these tanks would give no idea of their relative efficiency, because they cover too short a period. Tanks of this type function primarily when the filters are unloading. At such times their sedimentation efficiency may be high, but at other times, while solids are being stored in the filter these tanks serve no useful purpose, the influent and effluents being almost identical, or the effluent may even be worse than the influent.

A table showing such analytical results is not, therefore, included. They may be found in the analytical tables under the various plants.

FILTERS.

Trickling filters.—For the process of oxidation, the trickling filter holds at the present time the center of the stage. While special conditions may indicate other devices at some places, none are equal to the trickling filter for a combination of efficiency, economy, and capacity to stand abuse.

"The trickling filter is a bed, usually 5 to 10 feet deep, of coarse material such as clinkers, gravel, or broken stone, through which the sewage trickles in thin films."[5] It is almost universal practice in this country to apply the sewage to the bed by means of nozzles which act in a manner similar to lawn sprays. Mechanical distributors are used but these have never gained any popularity in this country.

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[5] American Sewerage Practice. Metcalf and Eddy, Vol. III, p. 555.

The oxidation is accomplished by a combination of direct aeration while the sewage is a spray in the air, and of the action of bacteria and other forms of life which grow in tremendous numbers within the bed and which act upon the sewage while passing through the filter. That the direct aeration is but a very minor factor in the process is evidenced by the fact that but little purification is accomplished by these filters until the bacterial zooglea and other forms of life have developed within the bed.

Eight plants using this type of filters were included in the survey. The structural features of these installations are contained in the following table:

TABLE NO. 50.—*Structural features of trickling filters studied.*

City.	Total area (acres).	Ventilators.	Rate m. g. a. d.	Average depth (feet).	Rate per cubic foot (gallons per day).	Filtering material.	
						Kind.	Size (inches)
Atlanta (Intrenchment)	2	Yes	2.5	5½	10.0	Granite	1½-2½
Atlanta (Peachtree)	2½	Yes	2.0	5½	8.0	do	1½-2
Baltimore	[1] 30	No	2.7-3	[2] 8½	7.3-8.1	Limestone and trap	1-2½
Columbus [3]	10	No	2.12	5½	9.1	Limestone	1-3
Fitchburg	[1] 2.1	No	[4] 2.7	10½	6.0	Trap and granite	1-2
Lexington	2	No	[5] 1.75	6	6.7	Limestone and granite	1-2½
Reading, bed 1	1	No	1.6	5	7.3	Slag	1½-4
Reading, bed 2	1	No	1.6	6½	5.6	Feldspar	1-2½
Reading, bed 3	1	No	1.6	5	7.3	Slag	3
Reading, bed 4	1	No	1.6	5	7.3	do	1½-4
Rochester (Brighton)	[1] 1	No	1.6	6	6.1	Dense limestone	1

City.	Dosing apparatus.	Static head on nozzles (feet).	Nozzles.		Lateral distributors	
			Type.	Spacing center to center (feet).	Location.	Flushing.
Atlanta (Intrenchment).	Siphon	8-1½	Merritt	13½	12 inches below surface.	Through nozzles.
Atlanta (Peachtree).	do	8-1½	do	13½	10 inches below surface.	Do.
Baltimore	Butterfly valve.	9±	80 per cent Merritt; 20 per cent Taylor.	15-21	33 inches below surface.	Do.[6]
Columbus [3]	Hand valve	8-4	Columbus, modified.	15½	42 inches below surface.	Do.[6]
Fitchburg	Siphon	10-1½	Worcester, modified.	15	At surface	Blow-off valves.
Lexington	do	9¾-2	Taylor (circular).	15	6 inches below surface.	Through nozzles.
Reading, bed 1	do	About 9-2½.	Reading	13½-15½	Bottom	Do.
Reading, bed 2	do	7½±-2½±	Weand	12½-13½	do	Do.
Reading, bed 3	do	About 9-2½.	Reading	13½-15½	do	Do.
Reading, bed 4	do	About 9-2½.	Weand	14½-15½	do	Do.
Rochester (Brighton).	do	6-0	Columbus	14½	36 inches below surface.	Blow-off valves.

[1] Entire filter area not used at one time.
[2] Partly submerged, 1½± feet during part of day.
[3] Plant not operated during winter.
[4] 1919.
[5] Estimated.
[6] Can flush direct, but this method not used.

TABLE No. 50.—*Structural features of trickling filters studied*—Continued.

City.	Underdrains.		Extent of control.	Pooling.	Surface flushing or cleaning.
	Type.	Flushing facilities provided.			
Atlanta (Intrenchment).	Half tile covered..	No........	Individual laterals.	None..........	Pick on surface.
Atlanta (Peachtree).	.....do............	No........	.....do..........	.....do........	Do.
Baltimore.........	Molded channels covered.	Yes.......	3-acre units.....	Little in winter.	Hose on surface
Columbus [a]........	Half tile..........	Yes, for main collectors.	2½-acre units....	Considerable..	Pick on surface.
Fitchburg.........	Molded channels covered.	Yes.......	Individual laterals.	None..........	Have broomed surface.
Lexington.........	Half tile..........	Yes.......	½-acre units.....	.....do.......	Nothing ever done.
Reading, bed 1....	.....do............	No........	¼-acre units.....	Some in fall, spring, and winter.	Surface raking.
Reading, bed 2....	.....do............	No........	Individual laterals.	.....do........	Do.
Reading, bed 3....	.....do............	No........	½-acre units.....	.....do........	Do.
Reading, bed 4....	.....do............	No........	.....do..........	.....do........	Do.
Rochester (Brighton).	Sloping bottom to tile.	Yes.......	Individual laterals.	None..........	Weeding.

[a] Plant not operated during winter.

At only two plants, those at Atlanta, are artificial arrangements provided to increase natural aeration of the beds. At these there are ventilators with cowls, but the chemist in charge of the plant does not feel that they are of any noticeable benefit. Some other installations have open rubble masonry walls, but there is nothing in the results of these to indicate that any aeration is needed beyond that inherent in the construction of all filters of this type.

The average per diem rate of treatment of the filters studied varied from 1.6 to 2.8 m. g. d. per acre with an average of 2.2. As it is known that the total surface area of the material in the bed is more important than the area of the bed itself, the depth of the bed must be considered. In the table are given the rates in gallons per day per cubic foot of filter material. These rates varied from 5.6 gallons for filter No. 2 at Reading, to 10 for the filter at the Intrenchment plant at Atlanta, Ga. With the exception of these two plants, and at Columbus, Ohio, the variations were between 6.0 and 8.1 gallons per day per cubic foot of filtering material.

At all except two plants dosing is done with siphons. Baltimore uses the butterfly valve and Columbus hand-operated gates. One filter at Reading was equipped with a butterfly valve, but as it was to be replaced in 1920 by siphon, it is credited with this change.

The underdrainage systems are of three types: (1) Sloping flat concrete bottoms overlaid with half tile which may or may not be covered with small slabs or plates upon which the stone rests. (2) The bottoms built with channels molded in them, and the channels covered with small slabs. (3) Bottoms sloping both ways to a drain in the trough of the slopes. This last is probably the simplest and least costly. It was found only at the Brighton plant at Rochester.

At all except two cities, Atlanta, Ga., and Reading, Pa., facilities were available for flushing the underdrains. It does not appear that these have been used very extensively except at one or two plants. However, the chemist in charge at Atlanta stated that such facilities were needed at his plants.

At only one plant was any appreciable amount of pooling observed, but operators at two others stated that they had some in the fall, spring, or winter. At none of the plants had this necessitated, as yet, any appreciable removal of filtering material or much labor on the beds. The surface at some had been loosened with a pick, and at others raking or brooming was practiced, and one plant employed a hose on the surface to flush out deposits.

At nearly all plants a hole was dug into the filters to determine the general nature and prevalence of life. It was not possible to make any detailed study or undertake any differentiation of species, so that no attempt has been made to correlate these observations with filter operation.

At the Intrenchment Creek plant at Atlanta the hole was dug to a depth of 1 foot. The surface stones were of good size with little small material, and clean. Below these there was more smaller stone and all were coated with a slimy mud, but not sufficient to indicate serious clogging. Life was not very abundant. There were very few gray moth flies (*Psychoda*) and the small white worm, usually occurring in small masses, was not observed. The small red spider, while present, was not abundant and there were some few white spiders similar to the red ones. There were also a few long thin red worms.

At the Peachtree Creek plant at Atlanta a 1-foot hole was dug. The top 3 to 4 inches contained considerable deposit, though apparently not sufficient to cause serious clogging. Below this the voids became more open, and, at the depth of 1 foot, were quite free. The filter fly was present, though not prevalent. No small white filter worms were observed. The red spider and some of the larger worms were found, but only in relatively small numbers. The most noticeable feature was the tremendous number of small snail shells. These were seen on the survey in limited numbers in the upper layers of other filters and were frequently present in large numbers in final effluents, but at this plant the top 2 to 4 inches of some sections of the filter was fairly loaded with them. An attendant at the plant stated that he had not found algæ growth prevalent where these shells were abundant.

At Baltimore a hole 2 feet deep was dug in one of the oldest and most used filters, and another about 1 foot deep in a filter used only part of each day. In the first filter the flies and white filter worms were very numerous to a depth of about 4 inches. The red spider was present in fair numbers but not to the extent observed in this same filter four days previous. They were found at depths of 20 inches, but at that depth appeared to be larger than those near the surface. A few angle worms were found below the top 6 inches and a long thin worm, three-quarters to 1 inch long and one-thirty-second inch in diameter. Both of these are probably more prevalent in lower sections as they appear in great number in the effluent. The filtering material was rather compact with small stone filling the voids between the larger stone, but the surfaces were fairly clean, without much slime or other deposits.

In the second filter, life was similar to that described just above, but all forms were less numerous. The spiders appeared, on the whole, to be slightly larger. In two instances these were observed feeding on gray flies, but in other instances the two species seemed to be indifferent to each other's presence.

As noted below, at several other places, extensive web spinning by the spiders had been frequently observed here. No diminution of flies was noted after this had taken place and the formation of webs took place during the day. These points are mentioned as being different from observations at Fitchburg, Mass.

Holes 1½ to 2 feet deep were dug in two filters at Columbus. In both cases the filtering material was found to be badly clogged, one to a depth of 2 feet and the other to a depth of 18 inches where the voids in the stone appeared to become more open. In the more completely clogged filter, life, with the exception of the fly, was very limited, only a few spiders and fly lavræ. In the other filter there was more life, but it was not abundant, consisting of the fly to a depth of 4 to 6 inches, some small angle worms, a few spiders, and a limited number of snail shells. From observation at the plant outfall into the river, it was evident that these snails were very prevalent in some parts of the filter. These filters are not operated during the winter, and the assistant chemist, in temporary charge, stated that the white filter worm had not been in evidence since the filters were put on a part-year operation schedule. The spider was, he stated, observed on the surface the first warm spring day before the filters are put in operation. No filter flies are noticed till after two to three weeks of operation. When the filters are operated regularly the spiders seemingly disappear, but if a filter is idle for an hour or two they swarm out on the surface and begin to spin webs, covering the entire bed in a day. If the spiders are very numerous, they have, on hot days, in 45 minutes to an hour, covered with a dense network of webbing the walkway over the filters which is 500 feet long and 2½ to 3 feet wide.

No excavation was made at Fitchburg, Mass., but the following information was given by the chemist in charge. The filters were put in operation in October, 1914. During the summers of 1915 to 1917, inclusive, the filter fly was very prevalent, predominating over the red spider. During 1918 and 1919 the flies were more abundant till extremely hot weather in July, when the spiders, working during the night, spun webs covering at times the entire filter area and the grass, trees, and poles adjacent to it. These webs would break loose and float off during the day and be respun in the night. This sometimes continued for two or three weeks. After this, the prevalence of flies was greatly reduced, though both the fly and spider continued to inhabit the beds. At the time of the survey, the latter part of June, 1920, both were seen in the beds, but the flies were not noticeable at any distance from the beds.

In addition to the flies and spiders, the white filter worm was very prevalent, at times spread over the surface of the stones but at other times collected into small masses or balls on the stone. Larger worms, 3 to 4 inches long, are carried off in the effluent but have not been noticed in the upper layers of the filters.

At Lexington two holes, each 12 to 18 inches deep, were dug. The surface stone was largely covered with a layer, about one-eighth inch thick, of greenish black algæ, but there was not enough to cause any pooling or serious clogging. Below the surface the stone was in good condition with the voids open. Life was only fairly abundant, a moderate number of filter flies, some long thin angle worms, a few spiders, and some other forms. None of the small white filter worms were observed.

Because of the differences in medium, construction, and age of the filters at Reading, Pa., shallow holes were dug in all of them. Two slag filters, Nos. 1 and 4, and the stone filter No. 2, all showed more or less surface clogging, the clogging material containing considerable hair. In this clogging material were great numbers of long, thin angle worms to depths of about 6 to 8 inches, the number appearing to be dependent upon the extent of the clogging, with the greatest number occurring in the most clogged filter, No. 4, and the smallest number in the least clogged one, No. 2. Filter No. 3, composed of 3-inch slag, contained little foreign material, and the voids were clear and open. The small white filter worm decreased with clogging, being present in large numbers in filter No. 3 but in relatively small numbers in No. 4. Filter flies and the red spider were found in all filters, the latter being present in great numbers, but the operator stated that he had never seen the extensive web spinning observed at some of the other plants. Some other forms of life, such as slugs, occurred in small numbers.

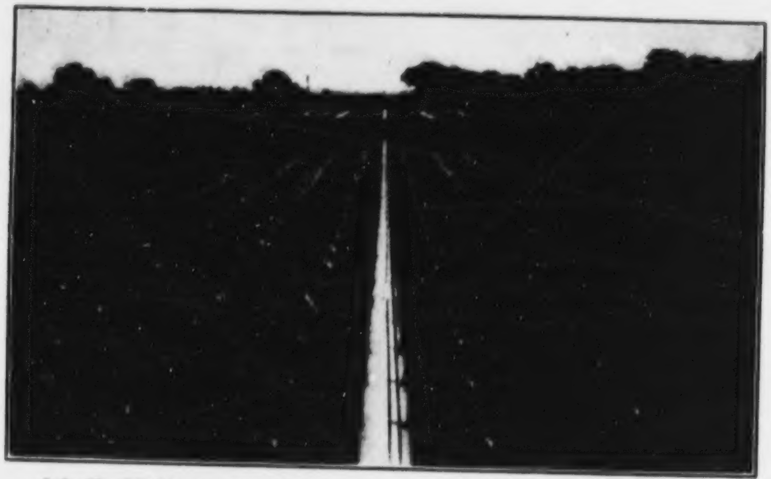

FIG. 27.—TRICKLING FILTERS. WITH IMHOFF TANKS IN BACKGROUND, AT COLUMBUS, OHIO.

FIG. 28.—CONTACT BEDS AT ALLIANCE, OHIO.

At the Brighton plant, at Rochester, N. Y., no hole was dug, and only conditions near the surface observed. There was no indication of serious clogging, the voids being well open. Filter flies, earth worms, and the filter worms were all present.

The results accomplished by the filters are shown in the following table of analyses. As with the other devices the methylene blue tests and chlorides results are not tabulated.

TABLE No. 51.—*Average analyses of influents and effluents of trickling filters studied.*

[Results in parts per million except as noted.]

City.	Suspended matter.			Settleable solids, 2 hours c. c. per liter.[1]		Oxygen consumed 30' in boiling water.			Alkalinity as $CaCO_3$ by M. O.			5-day oxygen demand.			Nitrates in effluent.
	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.	
Atlanta (Intrenchment)	67	42	34	0.6	Tr.	21	10.0	52	82	48.0	41	23	4.2	82	3.0
Atlanta (Peachtree)	68	38	44	.2	Tr.	18	7.0	61	69	35.0	49	20	3.9	81	2.0
Baltimore	107	46	57	.6	Tr.	35	14.0	61	144	63.0	56	125	14.0	89	3.3
Columbus	79	81	−2	Tr.	Tr.	46	29.0	37	219	192.0	12	134	40.0	70	.9
Fitchburg	63	52	17	Tr.	Tr.	37	19.0	57	99	7.9	92	95	20.0	79	6.1
Lexington	67	40	40	Tr.	Tr.	22	11.0	50	194	152.0	22	57	[2] 16.0	70	.....
Reading	85	48	44	Tr.	Tr.	31	16.0	48	177	105.0	41	90	20.0	78	4.4
Rochester (Brighton)	39	26	32	Tr.	Tr.	15	9.7	35	189	131.0	31	36	7.1	80	2.8
Average	72	47	34	.....	.....	28	14.0	50	147	92.0	39	77	17.0	78	....

[1] Tr. indicates less than 0.1 c. c.
[2] Effluent secondary sedimentation tanks.

Reductions in suspended matter run from −2 at Columbus to 57 at Baltimore. The Baltimore figure, however, includes removal by the fine screens located between the tanks and the filters. Very little importance can be attached to the amount of suspended matter in trickling filter effluents or the reduction in this constituent effected by them unless results are available for long periods. The amount of suspended matter in the effluent and its ratio to that in the influent will normally vary within wide limits, depending upon the state of the filter as regards unloading. The function of the filter, as regards suspended matter, is not to remove it permanently but to hold it till it has been worked over and oxidized. The character of the solids in the effluent is almost always entirely different from that of the solids in the influent, and it is this change of character that is important.

The alkalinity results are interesting in showing the reduction effected by the filters. An average of 39 per cent was removed. The greatest removal was effected at Fitchburg where the reduction was 92 per cent. This reduction is discussed under alkalinity in the section dealing with the value of various analyses (Ch. II).

The close agreement in the relative reductions in oxygen consumed and oxygen demand effected by all the filters is very noticeable.

With the exception of two plants, the reduction in oxygen consumed ranged within the relatively narrow limits of 48 and 61 per cent, and the range for all the plants for oxygen demand was from 78 to 89 per cent. If, as was planned, these filters are representative of their type at sewage treatment plants throughout the country where a reasonable amount of attention is given, they have well earned the good reputation and standing which they enjoy at the present time.

Contact beds.—The contact bed is one of the earliest oxidizing devices, representing "virtually the first logical step in evolving an intensive oxidizing machine following plain tank treatment."[6] It consists of a water-tight tank filled with broken stone or other similar material. Sewage flows into the bed, filling the voids in the stone, and is held in contact with the stone for a period called the contact period. During this time much of the suspended solids deposit on the stone, and, in addition, colloids and some dissolved solids are removed by adsorption or surface attraction. When the sewage is withdrawn from the bed, these solids are retained in the bed and eventually form on the stones a slimy coating within which great numbers of bacteria develop. As the sewage is withdrawn, air is pulled into the bed and the nitrifying bacteria in the coating on the stone reduce or oxidize the solids deposited.

An illustrative cycle of operation for three doses a day is given by Metcalf and Eddy[7] as follows:

	Hour.
Time of filling	1.0
Time of contact	.75
Time of emptying	.25
Time of resting	6.0
Time of cycle	8.0

The requirement for the time of filling is largely to permit the sewage to enter slowly enough to prevent breaking loose the coating on the stone. Some of the solids are removed during the filling. During the contact period the solids and colloids are further removed and the oxygen present in the bed, in the form of nitrites and nitrates in the stone coating, is used up by the sewage. If the contact period is extended after the oxygen is used up, putrefaction will set in to the detriment of the effluent. The time required for emptying is that sufficient to remove the sewage slowly enough to prevent its carrying away with it the deposits in the bed. It is during the fourth, or resting period, that the bacteria in the bed effect most of their work, attacking the deposits left by the sewage. The entire cycle of operation can be made automatic by timing siphons controlling the influent and effluent pipes.

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[6] Treatment and Disposal of Sewage. Hommon, Hoskins, Streeter, Tarbett, and Wagenhals, United States Public Health Service, Reprint 590.

[7] American Sewerage Practice, Metcalf and Eddy. Vol. III, pp. 229.

For this type of oxidizing device one-half million gallons per acre per day is generally accepted as an average nominal rate. Gradually the initial rate of a new bed is diminished by the retained solids filling the voids in the stone and reducing the sewage-holding capacity, and eventually the material in the bed must be removed and cleaned.

In this country the use of contact beds is limited, for the most part, to relatively small installations. They frequently are used to avoid pumping the sewage, as the loss of head through them is very little compared with trickling filters. They have an additional advantage of creating less odor nuisance than the trickling filter. For this reason they are selected at some places where the treatment plant can not be well isolated. Their limited capacity, however, together with the necessity of expensive cleaning, has largely eliminated them at the larger plants in favor of trickling filters.

The contact bed installations, at Alliance and Canton, Ohio, were included in this survey. At neither plant are these operated during the winter, both being shut down from about December 1 to May 1. At the time of the survey they had therefore been in operation, for the 1920 season, one to two months.

The following table contains structural and operating data of the contact beds studied:

TABLE No. 52.—*Structural and operation data of contact beds studied.*

	Alliance, Ohio.	Canton, Ohio.
Number of beds	17	16.
Area each bed, (acres)	[illegible]	[illegible]
Average treatment rates (thousand g. a. d.).	573	555.[1]
Bottoms	Some all concrete, others only partly concrete.	Concrete.
Nature of material in beds	4 beds have 18 inches slag ¾–1½ inches, 36 inches cinders ½–¾ inch; 8 beds have 48 inches cinders ½–¾ inch.	Top 5 feet slag ½–1 inch; bottom 12 inches slag 1½–3 inches.
Underdrainage	3-inch tile on 11-foot centers to 8–12 inch collectors.	6-inch half tile on 12–13 foot centers to main drain.
Application of influent	Diagonal duct filled with gravel	Diagonal duct filled and surrounded with gravel.
Control	Automatic	Selection by hand, operation cycle automatic.
Preliminary treatment	Imhoff and plain sedimentation tanks in parallel.	Imhoff tanks.
Filling period (hours)	2½–3 (estimated)	1.
Contact period (hours)	½ (estimated)	½.
Emptying period (hours)	2½–3 (estimated)	1.
Rest period (hours)	4½–6 (estimated)	20.

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[1] Sixteen beds receive a total of 14–15 doses per day. Operating beds treat 610,000 gallons per acre per dose.

The beds at Alliance are operated at much higher rates than those at Canton. It is probable that they could not maintain so high a rate at Alliance if the operation was continuous throughout the 12 months. They are, during the warm weather months, followed by intermittent fine cinder filters. The beds at Canton were designed to treat a larger flow of sewage than the plant was receiving at the time of the survey, up to 6 m. g. d., or 750,000 gallons per acre per day. It is questionable, considering the strength of the Canton sewage, whether this rate could be attained and maintained for the entire year without seriously affecting the character of the effluent.

Investigations of the condition of the material in the beds gave the following results:

At Alliance several holes were dug, varying from 2 feet deep to the bottom of the bed. The top 6 to 8 inches contained much fine material from the cinders, together with considerable muddy deposits, the voids being pretty well filled up. Below this the voids were more open, the cinders being of fairly uniform size below the top 12 inches. It was noticed that the clogging was greatest in the vicinity of the influent duct, decreasing toward the sides of the bed.

The small gray fly was found in the beds. These, it was stated, have never been noticed except in and in the immediate vicinity of the beds. In a hole dug June 3, while a bed was emptying, enormous numbers of red angle worms were found from 6 to 24 inches below the top. Four days later, however, when this hole was reopened and extended to the bottom of the bed only a relatively few of these worms were found. Nor were they found in any great numbers in any of the other three to four holes dug to depths of 2 feet.

At Canton a hole dug near the influent duct showed considerable clogging to a depth of 2 feet, the voids being pretty well filled up with a gritty deposit, probably small particles of slag from the filtering material. Another hole on the edge of the bed, distant from the influent duct, showed very little deposition, the voids being open. No worms or other forms of life were observed. It was stated that in previous years swarms of small white flies hovered over the bed for the first three to four weeks of operation in the spring. These flies were never observed more than 300 feet from the beds and for the most part stayed right on or over the beds. They were worse the first year of operation. None had been seen in 1920.

The analytical results obtained on the survey on the influent and effluent of these beds are given in the following table:

Table No. 53.—*Average analyses of influent and effluent of contact beds studied.*

[Results in parts per million except as noted.]

City.	Suspended matter.			Settleable solids, 2 hours c. c. per liter.[1]		Oxygen consumed 30' in boiling water.			Alkalinity as CaCO₃ by M. O.			5-day oxygen demand.			Nitrogen as nitrates.
	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Per cent removal.	
Alliance	69	17	75	Tr.	Tr.	38	26	32	122	107	13	69	20	71	2.8
Canton	93	41	56	0.3	Tr.	38	18	53	343	354	−3	98	22	78	0.3

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[1] Tr. indicates less than 0.1 c. c.

As discussed under trickling filters, the suspended matter determination for the short period covered by the analyses is of relatively little importance as the function of the bed is more to oxidize than to remove solids. Contact beds do not, however, unload to the extent trickling filters do, so that the suspended matter determination is of slightly more significance. The Alliance beds removed a greater per cent of the suspended matter than did those at Canton, but they fell considerably below the Canton beds in the removal of the oxygen consumed. The removals of the oxygen demand constituents is about the same at both places, and the residual demands almost identical. The nitrates in the effluent at Alliance are considerably higher than at Canton.

Intermittent sand or cinder filters.—This device was found at only one plant, Alliance, Ohio, where it is used only during the hot summer months and as a finishing process, treating the effluent from the contact beds.

For details of the design and operation of the Alliance filters, reference is made to the descriptions and discussions of this plant. The discussion here is confined to a brief statement of the principles involved and the position of this device in sewage treatment.

The intermittent fine filter is the most complete oxidizing device employed in sewage treatment, and in addition the most efficient clarifier. In operation the sewage is applied to the surface of the filter, usually by flooding from a radiating trough, and passed through the entire bed of sand or other fine material such as ground cinders or slag. After a dose of sewage has been applied the filter is allowed to drain and rest.

The suspended matter is largely strained out in the upper layers of the filter, and these form here a gelatinous zooglea mat. This eventually clogs the surface and has to be removed. The greatest oxidation is effected by the bacteria in the top 6 to 12 inches of the filter, decreasing by each succeeding foot.

In construction the beds are usually 4 feet deep. The filtering material is desirably as uniform as possible. Underdrains usually laid 3 to 4 feet deep at the upper end and spaced every 30 to 40 feet should be provided.

Filters of this type were originally used as one complete process of treatment, effecting both clarification and oxidation. At the present time, however, they are generally preceded by a sedimentation tank or both a tank and some form of filter. In the latter case they serve as at Alliance, as a finishing process where an effluent of unusually high quality is desired.

Because of the high cost of construction and operation and the low capacity of these filters their use is restricted to relatively small plants or for use as secondary filters, except where there are available large natural sand areas which can be converted to this purpose with relatively little expense. Such areas are available in many parts of the New England States and along the Atlantic coast, and it is to these sections that extensive use of these filters has been confined.

THE ACTIVATED-SLUDGE PROCESS.

The activated sludge process is the most recent promising development in the treatment of sewage. In "Sewage Disposal," published by George W. Fuller in 1912, no mention is made of this process, though the work of Col. W. M. Black and Prof. E. B. Phelps for the city of New York in 1910 is reviewed. Metcalf and Eddy (1) credit to this work by Black and Phelps the first serious attention in the United States to the aeration of sewage in tanks.

In a bibliography on the subject prepared by J. Edward Porter (2) the earliest reference in American or foreign press is the 1912 report of the Massachusetts State Board of Health. The experiments referred to in this report were largely preliminary to the present accepted process.

Since 1912 many investigators have studied different phases of the process, simplifying it and developing specially adapted apparatus and design features. The credit for the discovery and development of the method has been a subject of considerable controversy. In this connection Kinnicutt, Winslow and Pratt (3) gave as their conclusions that Dr. G. J. Fowler, of Manchester, England, "to whom is due the actual discovery of the activated-sludge process" admitted that "the illuminating idea which originated the work was due to a visit he paid while in the United States to the Mecca of sewage purification, namely, the experiment station at Lawrence, in the State of Massachusetts. Nevertheless, American engineers should reciprocate Doctor Fowler's graceful acknowledgment by recognizing that none of the investigations on this side of the water had really brought sewage aeration to a state of practical usefulness. It was the Manchester studies, and particularly the discovery of the effectiveness of previously aerated or 'activated' sludge in promoting oxidation, which really gave us this important method of sewage purification."

The most elaborate studies in this country have been made by the Sewage Commission of Milwaukee. On the basis of these experiments, this method has been adopted for the sewage treatment plant at present under construction there. The studies are still in progress.

Large scale thorough tests have been conducted at other cities in this country and in foreign countries. Of those in this country mention should be made of the Sanitary District of Chicago, Ill., Cleveland, Ohio; Baltimore, Md.; Brooklyn, N. Y.; Champaign and Urbana, Ill.; Houston, Tex.; Massachusetts State Board of Health, and Worces-

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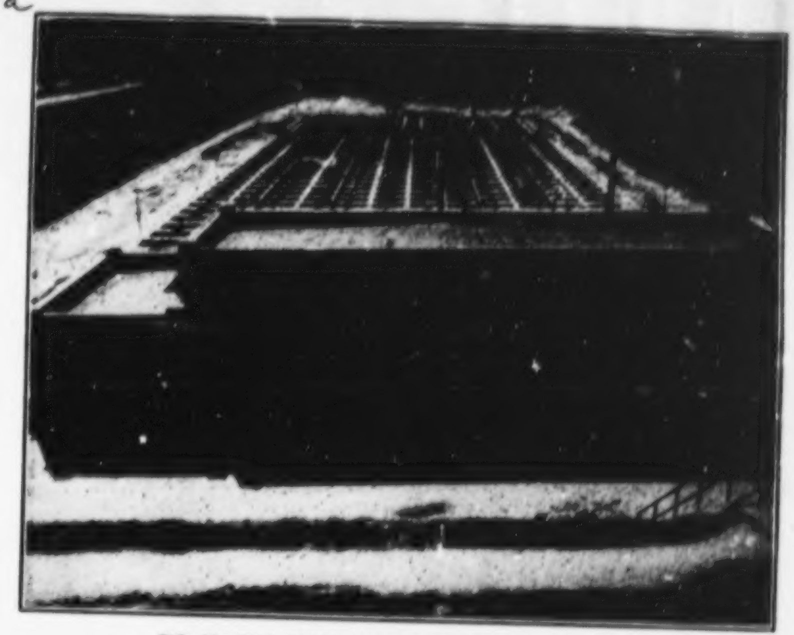

FIG. 29.—THE NORTH SIDE PLANT AT HOUSTON, TEX.

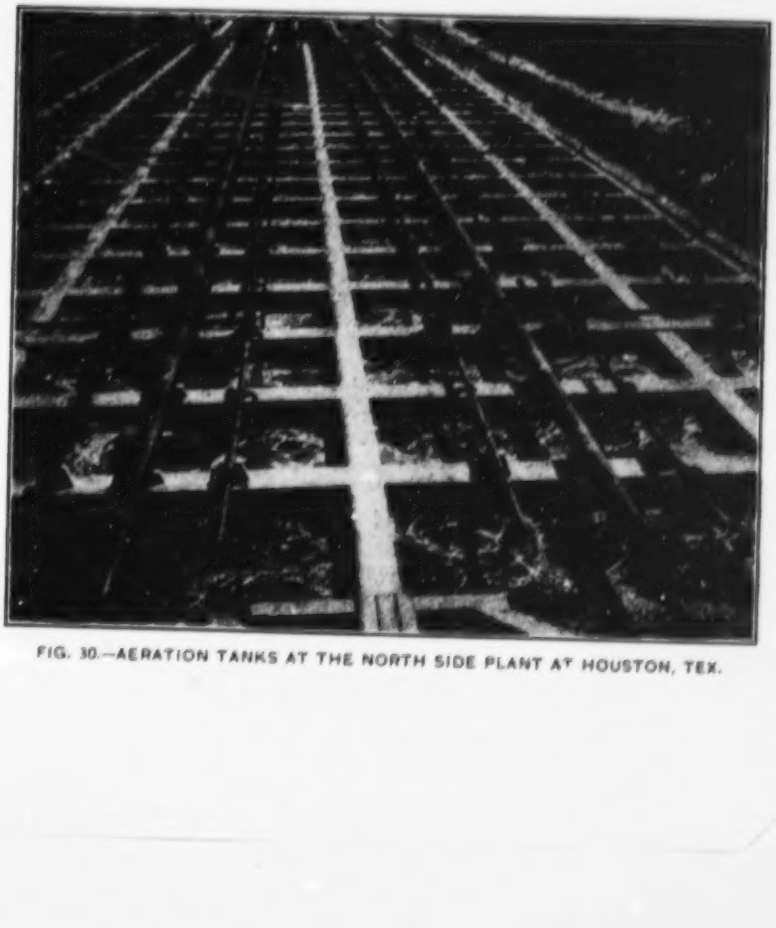

FIG. 30.—AERATION TANKS AT THE NORTH SIDE PLANT AT HOUSTON, TEX.

ter, Mass. This is not a complete list, but it includes most of the more prominent tests of this process.

The testing station at Urbana, Ill., operated in 1914, is one of the first if not the first exclusively activated sludge plant in the United States. The city reputed to have built the first plant for the entire sewage of the municipality is San Marcos, Tex., where the Sewer Co. of San Marcos installed a plant in 1915. This plant was one of those studied on this survey. At Houston, Tex., the two largest permanent plants in this country have been operating since 1917. These plants were also studied.

Activated-sludge treatment has been defined "as a biochemical process by which the purification of sewage is accomplished by passing it through tanks, in which sewage sludge is artificially agitated and intimately mixed with sewage and is supplied with the requisite oxygen for the optimum development of countless numbers of nitrifying organisms incorporated in and adhering to the sludge, and the final settlement of which causes a distant clarification of the oxidized sewage." (4)

As is the case with other sewage-treatment processes, the exact nature of the active agents and of the changes involved is not definitely known. Up to the present time study of the process has been devoted largely to the mechanical features of the apparatus used, and to the effect of varying physical conditions of operation. The details of the different physical, chemical, and biological reactions have not been determined. As a matter of fact, this statement is largely applicable to most of the sewage treatment processes.

A committee on nomenclature composed of Dallyn, Hammond, and Hatton, (4) divided the activated sludge process into the following treatments:

(*a*) "Economic screening," later defined as "such as may be most economical under the existing conditions. Probably through one eighth to one-sixteenth inch screen."

(*b*) "Preliminary rapid sedimentation in properly designed grit chambers where combined flow of sewage and storm water must be treated. It is quite essential to prevent detritus of heavy specific gravity, such as sand and gravel, from reaching the treatments which follow." Grit is defined as "that portion of the mineral solids carried in the sewage liquor which will settle out under a velocity of 1 foot per second."

Both of these steps are preparatory to the essential features of the activated sludge process. The screens may consist of the coarse bar screen with openings 1 inch or more, such as are common to all sewage-treatment plants. In addition to screens and grit chambers, where necessary, a preliminary sedimentation tank may be introduced, as at San Marcos.

(*c*) "Thorough mixing in aerating the sewage with activated sludge, which may be effected by means of air, by mechanical mixers, or a combination of both. In any case sufficient air for oxidation must be supplied to the mixture." Activated sludge is defined as "a flocculent sludge of medium brown color enveloped by masses of aerobic organisms possessing the power of rapidly oxidizing and nitrifying sewage, and which, though of low specific gravity, settles rapidly." It is further stated that activated sludge "must be of such a flocculent character as to absorb the collodial matter in raw sewage within a contact period of two hours and be of a golden brown color."

(*d*) "Sedimentation of the sludge contained in the admixture as it passes from the aerating tank. This may be accomplished by either horizontal or vertical flow sedimentation tanks."

(*e*) "The return of a portion of the settled activated sludge to the raw sewage before or at the time it enters the aerating tanks."

(*f*) "Reaerating the sludge which is returned to the raw sewage in separate aerating tanks. This may or may not be necessary, depending upon the character of the sewage treated and the effluent required." It can be noted here that this step is omitted at San Marcos, Tex. At this plant the sewage is very weak, but an effluent of very high character is obtained.

(*g*) "Secondary sedimentation for partially dewatering the separated sludge not returned to the raw sewage." In smaller plants where the volume of sewage treated, and, with it, the volume of sludge produced, is relatively small in comparison with the area available for drying or other means of disposing of the sludge this secondary sedimentation of sludge is not essential.

(*h*) "Sludge disposal. This may be effected in several ways. Where the climatic conditions are favorable, it may be dried in beds or lagoons in the open or under cover, and the residue used for filling in low ground, or for fertilizer, or burned. Under unfavorable climatic conditions it may be pressed or centrifuged and burned, or dried by artificial heat and the residue used as a fertilizer."

This brief outline of the process covers the essential principles of the successive steps involved. During the past five or six years many of the details of operation have been studied and some conclusions fairly well established. The process is safely beyond the experimental stage, but probably has not reached its final development. The problem of the disposal of the tremendous volume of sludge produced in excess of that needed for aeration with the sewage is at the present the greatest draw back to the method. This is true of other methods of treatment, but its seriousness is increased with this method because of the greater amount and the character of the sludge produced.

During this survey it was, of course, impossible to undertake any original research into the various steps or processes involved. It was, however, considered to be important to study the method under normal operating conditions. Results obtained under experimental conditions, even where these are on a scale comparable with those to be met in a permanent plant, do not always give a true indication of results to be expected when the supervision and skilled attention incident to experimental work are replaced by normal operating supervision. One of the first criticisms made of the activated sludge method was that it required for successful operation a degree of skill and training not likely to be found in operators at sewage-treatment plants.

The advantages and disadvantages claimed for the method as compared with a combination of methods, such as sedimentation and filtration, producing comparable results may be briefly summarized as follows:

I. Advantages:
  (*a*) The degree of purification obtainable is high.
  (*b*) The area required for the plant is small.
  (*c*) The initial cost of construction is low.
  (*d*) The loss of head is very slight, thus often eliminating the necessity for pumping sewage.
  (*e*) It is odorless (this claim may not apply to the disposal of the sludge).
  (*f*) The sludge produced is higher in nitrogen.
II. Disadvantages:
  (*a*) The volume of sludge to be handled is greatly in excess of that produced by other methods.
  (*b*) The character of the sludge renders handling more difficult.
  (*c*) Operating expenses are high.
  (*d*) There is much mechanical equipment to operate and maintain.
  (*e*) Temporary neglect, resulting in poor sludge, requires considerable time, 10 days to 3 weeks, to remedy, the plant meanwhile producing a poor effluent.
  (*f*) Industrial wastes, especially bactericidal chemicals destroy the purification cycle.

In addition to the above fairly well accepted advantages and disadvantages there are others more or less disputed. The bacterial reduction, found in many instances to be as high as 90 to over 99 per cent, is, without doubt, a favorable feature, but similar reductions have been obtained with trickling filters, and such reductions are not sufficient in cases where disinfection is required.

George G. Nasmith (5) in a paper before the Engineering Institute of Canada held that the activated sludge system is unsuitable for small communities or large institutions where an automatic system is highly desirable. This was disputed in discussion by F. A. Dallyn who had obtained favorable results from several small plants in the Province of Ontario.

R. G. Tyler (6) stated that power costs must be low and at least 1 m. g. d. of sewage treated for this method to be economical for small cities. The limit of 1 m. g. d. would largely limit the method to cities of over 10,000 to 12,000 population.

There is, however, some grounds for questioning the advisibility of emphasizing features of economy and automatic operation in designing sewage treatment plants for the smaller towns and institutions. In places where sewage treatment is not of sufficient moment to warrant a capable operator, the tendency of entirely neglecting the plant, and relying upon the automatic features is too common. Economy in maintenance and operation which is generally carried to an extreme in small plants, is not real economy.

With the activated sludge process it is conceded at the beginning that the mechanical apparatus requires a daily inspection of the plant. At San Marcos, Tex., this has been sufficient as a routine to insure a very high grade effluent.

There are too many small plants operating at nearly zero efficiency because they are "absolutely automatic," but these plants are not economic successes because they do not cost anything for maintenance or operation. The main expense for the operation of an "automatic" system is labor, but for the activated sludge system it is power. It is easy to reduce the pay or dispense entirely with the services of the labor and still maintain that the "automatic" sewage plant is operating. But dispensing with power at an activated sludge plant is equivalent to abandonment of the plant.

In addition, at small plants the disposal of sludge, which is the big difficulty holding back the adoption of the activated sludge method, is not such a serious problem, even in a relative sense. While the quantity produced per million gallons of sewage may be the same in a small as in a large plant, the total volume is so much less that disposal methods economically impossible at large plants may be perfectly feasible at small plants.

The development of a new process opens an unlimited field for variations of design and operation by different investigators. Up to the present time these have not become standardized, though several details have become fairly well established. In this country, for instance, the weight of opinion is in favor of filtros plates as air diffusers; the principle of continuous flow instead of fill-and-draw is so thoroughly established that only exceptional local conditions justify the use of the latter method of operation.

In the following table, factors of design and operation, so far as they were obtainable, for the plants surveyed are given, and, for comparison, data, more or less complete, on other plants, especially the more recent ones, are included. Much of the information was taken from a digest bibliography on activated sludge by J. Edward Porter (2). Wherever possible the original articles were consulted.

The plants given for comparison do not constitute a complete list of experimental, permanent, or proposed plants. Small test units to study the theory of the process, are not included. Others of comparable importance with some of those listed were omitted because adequate information concerning them was not available.

TABLE No. 54.—*Features of design and operation of activated sludge plants.*

City.	Type.[1]	Plant capacity, m. g. d.	Ownership.[2]	Sewage treated.[3]	Preliminary treatment.[4]				Aeration tank.			
					Grit chambers.	Coarse screens.	Fine screens.	Sedimentation.	Number of tanks.	Effective length (feet).	Effective width (feet).	Effective depth (feet).
Houston, (north side) (7)	P	[5] 10.0	M	N. S.	×	×	.....	.....	4	280	18	9.75
Houston, (south side) (7)	P	[5] 5.0	M	S.	×	×	.....	.....	2	280	18	9.75
San Marcos, Tex. (7)	P	[6] .2	P	S.	.....	.....	×	×	1	145	3.8	16
Sherman, Tex. (7)	P	[6] .35	M	N. S.	×	×	.....	.....	2	200	8	12
San Angelo, Tex. (8)	P	[5] .4	P	S.	.....	.....	.....	×	1	.....	.....	.....
Des Plaines River, Ill. (9)	D	3	([7])	S.	×	×	×	.....	4	260	7.6-15	10, 15
Worcester, Mass (10)	E	.075-.125	M	I. S.	×	×	.....	.....	1	80	4.7	11.5±
Pasadena, Calif. (11)	E	.05	M	S.	×	×	.....	.....	1	60	3	10
Syracuse, N. Y. (12)	E	.....	M	S.	×	×	.....	.....	1	12	4	10±
Champaign, Ill. (13)	E	.144-.216	([8])	S.	×	×	.....	.....	1	105-140	3.2	9.5
Cleveland, Ohio (14)	E	.280-.470	M	S. I.	×	×	.....	.....	4	30	9.3	14.5

City.	Sedimentation tank.				Reaeration tank.				Operation.[9]	Diffusers.	Ratio diffusers to surface area, 1 to—	Aeration period, (hours).
	Number of tanks.	Effective length (feet).	Effective width (feet).	Effective depth (feet).	Number of tanks.	Effective length (feet).	Effective width (feet).	Effective depth (feet).				
Houston (north side) (7).	40	18.8	10	22.8	4	384	3-9	10.8	C	Filt...	7.5	2.7
Houston (south side) (7).	20	18.8	10	22.8	2	384	3-9	10.8	C	...do...	7.5	2.6
San Marcos, Tex. (7).	1	20	10	25	0	.....	.....	.....	C	...do...	11.4	3.5+
Sherman, Tex. (7)	2	28.4	21.9	15.2	2	230	2	12	C	...do...	8.0	[5] 2.3
San Angelo, Tex. (8).	1	20	18	25	.....	.....	.....	.....	Day C	Pipe...	.....	.....
Des Plaines River, Ill. (9).	12	24	24	15±-19.25	2	250	7.6	10	C	Filt...	5.7 5.9	.....
Worcester, Mass. (10).	1	14 diam.		20±	1	12	5.3	11.5±	C	...do...	5.2	4-6
Pasadena, Calif. (11).	2	16	6	.....	1	12	6	10	C	...do...	8.5	4
Syracuse, N. Y. (12).	1	4	4	15±	1	4	4	13±	C	Pipe...	.....	.....
Champaign, Ill. (13).	1	10.5	6	11	1	26	3.2	9.5	C	Filt...	.....	4-6
Cleveland, Ohio (14).	1	30	9.3	30	1	30	9.3	17.3	C	...do...	5	1.1-3.0

[1] P=permanent plant. E=experimental. D=designed but not built by January, 1921.
[2] I=industrial or institutional. M=municipal. P=private.
[3] I=industrial wastes. N=night soil. S=sewage.
[4] × indicates presence.
[5] Design basis.
[6] As operating.
[7] Sanitary District of Chicago.
[8] Illinois State Water Survey.
[9] C=continuous.

TABLE No. 54.—*Features of design and operation of activated sludge plants*—Contd.

City.	Sedimentation period (minutes).	Reaeration period (hours).	Per cent sludge returned.	Air used, cubic feet per gallon.	Air factor.[10]	Cap. m. g. d. per acre aeration tank.	Vol. sewage treated per aeration tank m. g. d.	Method of sludge disposal.[11]	Sewage treated per square foot sedimentation tank, gallons.	
									Design.	Operation.
Houston (north side) (7).	60	4	15-25	1.5	140	[9] 22	3	L. or T. P. D.	1,300	1,064
Houston, (south side) (7).	70	5.5	20	1.7	124	[9] 23	1.5	L.	1,330	800
San Marcos, Tex. (7).	60-120	0		1.6	112	[9] 15	.2	D		1,000
Sherman, Tex. (7).	[8] 60	[8] 2.5		4.1	307	[9] 8	.3	A		540
San Angelo, Tex. (8).										1,100
Des Plaines River, Ill. (9).						9-16		C.D.P.T.		
Worcester, Mass. (10).	100-175	3-6.5	16-30	1.7-5.0	139-375	6.5-15	.075-.135	B. P. T.		
Pasadena, Calif. (11).	30	(7)	10-30	1.6	65	12	.05	B. T.		800
Syracuse, N. Y. (12).										
Champaign, Ill. (13).	24-37			2	160	13-20		B. P. C. D.	1,917	
Cleveland, Ohio (14).	40-67	1.1-4.5	25-34	.74-1.30	80-141	26-75	.28-.40	B. P. C. T.	1,918	

[8] Design basis.

[9] As operating.

[10] Air factor = products of cubic feet free air per cubic foot of sewage by feet of air submergence. When submerged figure was not known it was assumed to be depth of tank, less 1½ feet free board.

[11] A = dilution into stream; B = beds; C = centrifuge; D = drier; L = lagoons; P = presses; T = concentration tanks.

It is difficult and sometimes impossible to arrange in tabular form data published from experimental plants. The design and methods of operating these plants are so changed and varied during the tests that a correct statement of dimensions and operating factors are possible only with a confusing number of footnotes or explanatory paragraphs. In the following discussion of individual items in the table, data from some plants not listed are included.

PRELIMINARY TREATMENT.

Grit chambers.—There is a general agreement among engineers and operators that heavy inorganic solids must be excluded from the aeration tank. When the sewage, therefore, contains any appreciable amount of grit, grit chambers must precede the aeration tank. Grit in the aeration tanks will either settle over and clog the air diffusers, preventing uniform and thorough agitation and aeration, or will necessitate the use of an extravagant amount of air.

Messrs. Dallyn, Hammond, and Hatton (4) include as part of the activated sludge process "preliminary rapid sedimentation in properly designed grit chambers where combined flow of sewage and storm water must be treated. It is quite essential to prevent detritus of heavy specific gravity, such as sand and gravel from reaching the treatments which follow."

The elimination of grit as preliminary to sedimentation is well established, but its presence is even more undesirable in aeration tanks than in sedimentation tanks. Of the plants listed above only two are not provided with grit chambers, and these have presedimentation tanks.

Coarse screens.—Those, which are considered to include all screening devices with openings larger than one-half-inch, are in the same class as grit chambers. They serve to remove large particles which are not amenable to tank treatment, interfere with the aeration process, and admit of more economical disposal if handled by themselves.

Fine screens.—On the value of fine screens there is less agreement. Hatton (15) as a result of the Milwaukee tests advocates the use of fine screens. "We found at Milwaukee we could save from 15 to 20 per cent air when treating a sewage passing a 20-mesh screen as compared with the same sewage passing a 1-inch grid screen." He also found it helped smooth plant operation. The reasons for the fine screens may be, however, largely local. "The character of sewage produced in Milwaukee creates in the aerating tanks large masses of of hair, lime, entrails, leather findings, pieces of hide and back; these are constantly deposited upon the surface of the diffuser plates, interfering with their efficiency and stopping up the orifices to sludge pumps." (15) Where a purely domestic sewage is to be treated by the activated-sludge process, the author, Hatton, is not so sure that such fine screening is necessary. He believes that a three-sixteenth-inch slotted screen is fine enough for any sewage.

Pearse (16) concluded from his experiments at the Chicago Stockyards that "the use of the fine screen (20–30 mesh) seemed advisable to remove much comparatively inert material which is slow to oxidize. The runs made with a screen did not appear to differ greatly in character of effluent from those without. The coarser material, however, deposited in various undesirable places, when the screen was not used, and additional air was required to keep it in suspension." These conclusions apply to the treatment of stockyard wastes, but the design for the Des Plaines River plant prepared by and under the direction of Mr. Pearse and treating domestic sewage provides for fine screening.

G. B. Gascoigne (17) questioned, from the results obtained at the Cleveland activated sludge testing plant, the necessity or economy of fine screens. The sewage treated at this plant, while fairly strong, has its solids in finely divided state as a result of long travel in the outfall sewer.

None of the plants visited on this survey had fine screens with the exception of San Marcos, which has a one-fourth-inch mesh over the outlet pipe of the septic tank which precedes the aerating tanks.

Other plants in this country and abroad, both experimental and permanent, are operated for the most part without fine screens.

The advisability and economy of fine screens as preliminary treatment to the activated-sludge process does not appear to be definitely proven, at least not for universal application. For large installations and when the solids, especially those from industrial wastes, are large, the fine screens may pay for themselves. But it is questionable whether their installation would be an economy at the average plant treating domestic sewage.

Preliminary sedimentation.—This has not been considered favorably by many investigators. The activated-sludge process has been viewed as a complete process in itself, performing the functions of both clarification and oxidation or, as at Cleveland, only clarification. With the ability of the process to perform both of these functions once well established, investigation has turned to the disposal of the by-product, the large amount of sludge. This sludge is, for sewage sludges, so relatively high in nitrogen that the development of an economically practical method for utilizing the value of this nitrogen in the disposal of the sludge has been the object sought by most investigators.

With this idea foremost, the use of preliminary sedimentation has been discounted. Hatton stated (15):

> Preliminary sedimentation, in lieu of fine screening is not applicable to the activated-sludge process if the sludge is to be disposed of finally as fertilizer. The sludge from such a tank contains very little ammonia, is hard to handle and mix with activated sludge, and when mixed adds to its weight without adding correspondingly to its value; whereas, fine screenings contain almost as much available nitrogen as the activated sludge, can be easily mixed with it in the dryer, and increase the value of the mixture to a proportionate extent.

While many experiments have been encouraging, giving promise of economic methods of disposing of surplus activated sludge as a filler or fertilizer with a revenue at least equal to the cost of handling the sludge, and possibly more, there is, at this time, no activated-sludge plant actually disposing of its sludge through this channel.

The majority of the permanent plants at present operating in this country are small, and produce too little sludge to justify the installation of an expensive plant for its preparation as a fertilizer base. For plants of this size the use of a preliminary sedimentation tank to remove most of the settleable solids before aeration, and possibly to serve as a digestion tank for excess activated sludge, is worthy of consideration. By this tank the sludge would be prepared for drying on beds and the total volume to be handled greatly reduced. With such an arrangement the aerating tank practically replaces a trickling filter or other oxidizing devices.

AERATION TANKS.

After the period of retention in the aerating tank and the volume of liquor to be treated are decided, the tanks should be so proportioned as to give the greatest length of flow possible without wasteful use of piping and concrete. (15.)

The predominating shape of aeration tanks is long and narrow. In many, the length is obtained by longitudinal baffles diverting the flow back and forth two to four or five times. Of the plants listed in the preceding table the ratio of width to length varies from 1 to 3, to 1 to 38, taking in the extremes represented by the experimental unit at Syracuse, N. Y., and the permanent plant at San Marcos, Tex. The two plants at Houston and the one at Milwaukee have the same ratio, about 1 to 15.5. With the exception of the small experimental tanks at Syracuse and the one at Cleveland, which latter was designed for clarification only, the ratio of 1 to 15.5 is the lowest of any plant listed in the table.

Some tests have been run with circular tanks at Baltimore, Md., where an existing Imhoff tank was used, at Milwaukee during the early tests, and other places, but the opinion now is predominantly in favor of rectangular tanks.

In the above table the Milwaukee tanks provide the greatest effective depth with those at Cleveland only 6 inches shallower. This depth was adopted at Milwaukee as a result of tests made with a 10-foot and a 15-foot tank run in parallel. Eddy, Fales, Copeland, Ferebee, and Hatton, (18), on the basis of the results obtained, reached, among others, the following conclusions:

> There was a slight difference in favor of the 15-foot depth of tanks, not taking into consideration the extra cost of compressing the air for a 15-foot depth of liquor over that for a 10-foot depth.

The Sanitary District of Chicago, (19), in designing the Des Plaines River plant, provides both 10 and 15 foot aerating tanks to test the relative efficiency of these depths for the local conditions there. For the most part the depths at the other plants are fairly close to 10 feet.

The use of filtros plates as air diffusers is well established in this country. Some investigators have obtained good results with perforated pipe, but where these have been tested in parallel with porous tile, wood blocks, and filtros plates, the almost unanimous verdict has been in favor of the last named. Among the more important studies of diffusers were those made by Hatton and Copeland at Milwaukee and Bartow at Urbana.

A number of mechanical agitating devices have been tried out with varying success, but none have received any general recognition as a substitute for the air agitation with filtros plates. They offer a possible field for future development. It has been demonstrated that only a small per cent of the air used in the aeration tanks is necessary for the oxygen taken up by the sewage, and that the bulk of the air is of value purely for agitation. Haworth (20) described a mechanical agitator used in tests at Sheffield, England. Surface absorption was the only source of oxygen for the sewage. The question is largely one of efficiency and economy, with the best evidence so far in favor of air diffusers as against mechanical agitation.

The ridge and furrow or saw-tooth bottom is almost standard for plants in which the aerating chamber is wide enough to provide for two or more filtros plates. The hopper bottom, each hopper containing one plate, is a modification of the ridge and furrow bottom, the main idea being to confine all flat-bottom surface upon which sedimentation is likely to occur to the area occupied by the filtros plates. The slopes on the ridges should be adequate, 1 to 1, or to 1.5, to prevent any accumulation of sludge. Some good results have been obtained in tests with flat-bottom tanks using mechanical devices to prevent sedimentation of sludge, but their use so far has been decidedly the exception.

The ratio of air diffusers to tank surface as given in Table No. 54, shows fairly wide variation. Hatton (15) stated: "The economical ratio depends largely upon the type of aerating tanks used and the character of effluent required." In 1917 he had designed the Milwaukee permanent tanks on a 1 to 6 ratio, but as a result of subsequent experiments changed to 1 to 4.5. The Cleveland experimental units in 1916 were designed with a 1 to 5 ratio in spite of the fact that clarification only was sought. For the most part the ratios are higher, running around 6 to 8. The San Marcos plant with a ratio of only 1 to 11.4 produces an exceptionally good effluent, but the sewage is very fresh, unusually weak, and is presettled before being aerated. In England the ratios run lower than in this country, two plants at Manchester having ratios of 1 to 10 and 14.

The capacity of the tanks, upon which the aeration period largely depends, is generally designed to give aeration periods, on a total displacement basis, of from 2½ to 8 or 10 hours, for sewages, and longer, up to 20 hours where there are large amounts of industrial wastes. From results obtained in the Milwaukee tests, Hatton, Eddy, Fales, Copeland, and Ferebee (18) agreed that "with properly baffled tanks, 4 hours on domestic sewage would probably be all that was required." For Milwaukee, the units designed provide for 6 hours aeration under normal flow. This is for operation without reaeration of the sludge. Pearse (16) found at the Chicago Stockyards that during the same period of the year he obtained about the same results with 9-hour aeration without reaeration as he did with 6.6 hours aeration with reaeration. In the test at

Cleveland, Pratt and Gascoigne (14) report aeration periods as low as 1.1 hours where reaeration was used, but in these tests clarification was the main result sought. As a result of their tests they concluded that an average of 3 hours would accomplish the results desired. Three and one-half hours is sufficient at San Marcos to produce a highly oxidized stable effluent from a weak, fresh, presettled sewage.

While 6 hours is a fairly representative figure to use in general discussion it may vary considerably both ways depending upon the character of the raw sewage, the degree of purification desired, the temperature, the amount of sludge returned, and the volume of air used.

It has been found in comparative tests that an 8-hour aeration period requires only about half as much air as a 4-hour period. Air is used for two purposes, first, to provide oxygen required for the reduction of the organic matter in the sewage, and second, for agitation. The amount of air necessary is determined by the latter requirement, as only a very small part of the available oxygen in the air is used by the sewage. Crawford and Bartow (21) found the oxygen used by sewage to be 5 per cent of that available, and Eddy (22) found only 10 per cent of the oxygen disappearing from the air used with strong tannery wastes.

Eddy (22) gives, as a general statement—

> Where aeration is carried out in continuous flow tanks of 10 to 15 feet depth, with area of diffuser plates in proportion of 1 to 6 of tank area and a period of agitation of about 6 hours, the quantity of air may be about as follows:

	Cubic feet per gallon.
For rather weak domestic sewage	1.0
For strong municipal sewage containing considerable industrial wastes not particularly detrimental to bacterial life	1.5
For weak municipal sewage containing considerable industrial wastes some of which are detrimental to bacterial life as, for instance, acid iron wastes	2.0
For strong municipal sewage containing considerable industrial wastes some of which are detrimental to bacterial life as, for example, acid iron wastes	4.0
For municipal sewage containing sufficient industrial wastes not specifically inhibitive of bacterial life to decidedly influence the composition of the sewage, e. g., packing house, tannery, etc	3.0
Strong packing house waste	4.0
Strong tannery wastes containing a very large proportion of colloids but settled before aeration	6.0

In the majority of activated plants provision has been made for the aerating alone, or the reaerating, of the sludge before its addition to the raw sewage. The reaerating tanks are generally of similar construction to the aerating tanks, though this is not essential. Unless special provisions are made for air control, however, the depth of the two tanks must be the same or the air will take the path of least resistance through the more shallow tank.

REAERATING TANKS.

There is some difference of opinion regarding the value of reaerating sludge between its removal from the sedimentation tank and its addition to the raw sewage. Hatton (18) is not including reaeration tanks in the design of the permanent Milwaukee plant.

> It was hoped that by reaerating the sludge the aerating capacity might be reduced, due to a richer sludge, but our experiments indicated that this was not a fact, at least to the extent of warranting us in providing extra tankage and air for reaeration.

On the other hand Pearse (16) reports a probable saving of 20 per cent of tank volume by reaerating together with a reduction in the period of aeration and a slight saving in air consumption. At the Des Plaines River plant of the Sanitary District of Chicago (19) provisions are made to test the value of reaeration for local conditions and the tanks are so designed that with minor modifications they can be included or omitted.

Three of the four plants studied on the survey employed reaeration. At Houston one-third of the air was used in this tank and the detention period was over twice that in the aeration tank. At Sherman the sludge was reaerated, but there was available no data regarding the operation of the reaeration tank. At San Marcos reaeration was omitted.

SEDIMENTATION TANKS.

On leaving the aerating tanks the sewage with the contained activated sludge passes to sedimentation tanks for the separation of the sludge from sewage.

These tanks must provide a detention period long enough and surface area adequate for the sludge to settle; must have a sufficient depth to prevent the sludge being carried out with the effluent; and must provide means for the removal of sludge.

The detention periods as given in Table No. 54, vary from 24 minutes at Champaign, Ill., to nearly 3 hours at Worcester. Hatton (15) stated in 1917, "the detention period may be from 30 to 50 minutes according to the character of the sewage." From later tests he concluded that to obtain concentration at least 1 hour should be allowed for settling and that the maximum velocity of flow should not exceed 1.5 feet per minute. Pratt and Gascoigne (14) tested periods as low as 35 minutes without claiming to have reached the lower limit. The corresponding velocity was 1 foot per minute. While the shorter periods are effective under normal conditions, the effect of operation during cold weather or with underaeration is to produce a voluminous fluffy sludge requiring longer periods for

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FIG. 31.—INTERIOR VIEW OF REAERATION TANK AT THE NORTH SIDE PLANT AT HOUSTON, TEX.

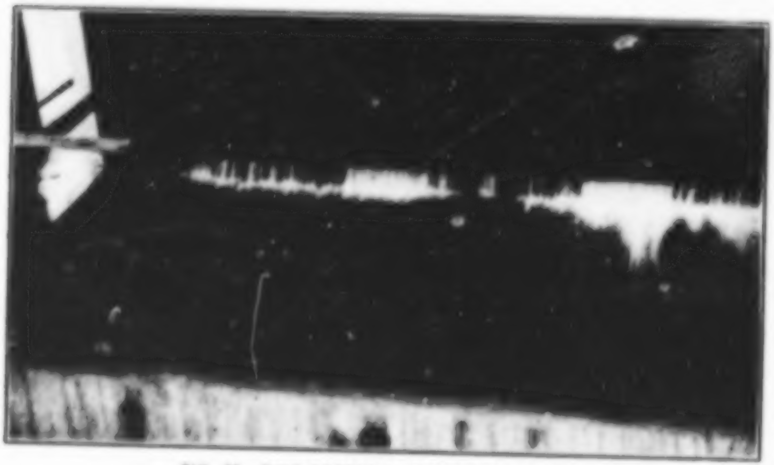

FIG. 32.—FINE SCREENS AT BALTIMORE, MD.

renewal. Alvord, Eddy, and Fuller (23) placed 1 hour sedimentation under maximum flow as basic.

Considerable attention has been given to the depth of the sedimentation tanks. The Milwaukee tests indicated for local conditions a minimum requirement of 15 feet. Because of the lightness of the sludge it is very susceptible to changes in the rate of flow, and the volume occupied by the sludge is dependent on its condition. The data at present available indicates a minimum depth of 15 feet. For the most part the sedimentation tanks have been deeper in order to provide hopper bottoms for concentration of the sludge to the point of removal. The slopes on these hoppers must be steep to prevent deposition and septic action. Pearse (16) found that, to prevent this, the slopes should be about 2 vertical to 1 horizontal. At Houston slopes of about 1¾ to 1 at the south side plant were changed to more than 2½ to 1, those at the north side, however, were left at 1¾ to 1. At San Marcos the sedimentation tank was remodeled to give bottom slopes of 2 and 2½ to 1. At Cleveland slopes of 1 to 1 proved too flat and were changed to 6 to 1 and 9 to 1.

Such slopes necessitate tanks either very deep in proportion to their surface area, or with a number of hoppers which multiply the number of points at which sludge must be removed.

Flat-bottom tanks equipped with mechanical devices to carry the sludge to a central point for removal have been tested with satisfactory results. Pearse (16) claims that more concentrated sludge is thus obtained which is an advantage in permitting smaller units and smaller return sludge channels. There is the added advantage of greatly reducing the volume of sludge to be returned and to be disposed of.

The settling area is of utmost importance in the design of sedimentation tanks. Pratt and Gascoigne (14) give data that would indicate 1,000 gallons per square foot of settling area as a safe figure. They obtained satisfactory results with rates of 2,400 gallons. The Milwaukee tests indicated that a satisfactory result could be obtained with rates of 1,600 to 2,000 gallons. To make conservative allowance for changes in the condition and volume of sludge, 1,600 gallons of effluent per square foot was adopted to care for the maximum flow, or about 850 for average dry weather flow.

The Houston sedimentation tanks were, in 1920, handling average flows of about 1,050 and 800 gallons of effluent at the north and south side plants, respectively. The design for ultimate capacity of both plants was about 1,300. At San Marcos the average flow was equivalent to 1,000 gallons per square foot.

Until new evidence is produced rates of 800 to 1,000 appear to be the most logical to use in design.

OPERATION.

Operation difficulties of activated sludge plants are gradually being ironed out. The reasons for unfavorable conditions are being found and with them the corrective measures. In the early stages of its development it was generally held that the adjustment of conditions to secure proper functioning of the plants required such skilled and technical operation as to preclude adoption of this process except at the very large cities. This subject has been discussed elsewhere, and it is only necessary to state here that this attitude is being seriously questioned on the basis of results obtained under average plant operators.

Several features of operation such as the aeration period, volume of air necessary, and the settling period have already been taken up under different devices.

In general, while for any plant there is a fairly wide range for the various factors within which operation will proceed satisfactorily, the result of exceeding these limits is disastrous.

It is known that if aeration is not adequate the resulting sludge will be light and voluminous, failing to concentrate properly in the sedimentation tank, and necessitating the return of extravagantly large volumes to the aeration tank for mixture with the incoming sewage, and correspondingly large volumes to be disposed of. Eddy (22) calls attention to the fact that assuming a plant to operate with 20 per cent returned sludge containing 2 per cent solids, a change in the sludge to 0.5 per cent solids would necessitate the return of four and one-half times as much sludge to maintain the same relation of solids.

Low temperature conditions may result in a similar condition of the sludge, and it has generally been found necessary to use more air in the winter than in the summer.

On the other hand overaeration causes a return of the colloids removed from the sewage and contained in the sludge to the sewage, with a resulting poor effluent.

The character of the sludge is also largely dependent upon the sedimentation period. If this is too short the sludge can not concentrate, but if too long, say over six hours, septic action, which ruins the sludge, is likely to start.

At the present time plant operators can best judge the condition of their sludge by its visible appearance and properties. Good sludge is, for normal sewage, golden brown in color and settles very rapidly.

The amount of sludge returned to the aerating tank depends on the concentration to be maintained. This concentration is expressed as the per cent by volume of sludge to total volume of the mixture of sewage and sludge in the aerating tank. This factor appears to admit of great variations without materially affecting the effluent. From 15 to 30 per cent or more has been used, with an average around 20 to 25 per cent.

RESULTS OBTAINED.

With but few exceptions the effluents from activated sludge plants have been very good. In Table No. 55 the results obtained from the four plants surveyed are given together with reported results from other places. The analyses selected for this table are those which indicate the extent of clarification and the extent of oxidation. Because of the different determinations used at different places to measure these results it is, unfortunately, impossible to put all plants on a comparable basis.

TABLE No. 55.—*Analytical results obtained at nine activated sludge plants.*

[Results in parts per million except as noted.]

City.	Total aeration hours.	Settling minutes.	Suspended matter.			Settleable solids, 2 hours c. c. per liter.[1]		Oxygen consumed 30′ in boiling water.		
			Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Influent.	Effluent.	Per cent removal.
Houston, north side (7)	6.7	60	206	17	92	2.5	Tr.	45	10	78
Houston, south side (7)	8.1	70	225	7	97	2.0	Tr.	38	6.4	83
San Marcos (7)	3.5	....	42	3	93	Tr.	Tr.	18	8.5	53
Sherman (7)	....	....	264	73	72	5.0	3.4	64	32.0	50
Mount Vernon, N. Y. (26)	8–10	....	245	20—	92	....	....	[2] 154	31.0	80
Milwaukee (24)	....	....	318	11	97	....	....	132	27.0	80
Cleveland, Ohio (14)	5.3	90	231	30	87	....	....	59	15.0	76
Urbana, Ill. (13)	....	....	....	....	....	....	....	55	20.0	64
Worcester, England (25)	8	150	104	Tr.	....	....	....	[3] 76	[3] 21.0	72

City.	Oxygen demand 5-day, 20° C.			Dissolved oxygen.		Nitrogen as—			
						Ammonia.			Nitrates in effluent.
	Influent.	Effluent.	Per cent removal.	Influent.	Effluent.	Influent.	Effluent.	Per cent removal.	
Houston, (north side) (7)	115	11.0	91	0.2	5.2	17	4.3	75	4.6
Houston, (south side) (7)	112	7.4	94	.8	7.4	18	1.7	91	3.0
San Marcos (7)	57	16.0	72	2.8	7.6	17	2.8	84	8.8
Sherman (7)	165	33.0	80	2.5	6.2	26	23.0	12	1.2
Mount Vernon, N. Y. (26)	....	....	....	....	....	....	....	....	1.0
Milwaukee (24)	....	....	....	....	....	15	13.0	13	.9
Cleveland, Ohio (14)	....	....	....	....	....	11	8.4	24	....
Urbana, Ill. (13)	....	....	....	....	....	24	0	100	19.0
Worcester, England (25)	....	6.3	....	....	....	20	26.0	−30	....

[1] Tr. indicates less than 0.1 c. c. [2] Method not stated. [3] Computed from 4-hour determination.

With the exception of the Sherman plant, the suspended solids in the effluents are all low. At Sherman the sludge or "floc" was being carried over from the final sedimentation tank. It was very light and voluminous, as can be seen from the settleable solids results where 73 parts of suspended matter occupied 3.4 c. c. in the settling glasses. The sludge in the tanks at the time the analyses were made was comparatively new, most of the old sludge having been withdrawn shortly before. It appeared to be underaerated.

The oxygen demand results on the plants surveyed are with the exception of Sherman less than the available oxygen present in the form of dissolved oxygen and nitrates.

The use of the ammonia nitrogen determination as an indicator of the completeness or efficiency of aeration is discussed under analytical methods. Applying it to the results in the above table, the statement made above regarding Sherman is confirmed. With Milwaukee and Cleveland the ammoniacal nitrogen determination would indicate aeration to the point of clarification, but with relatively little oxidation. The nitrates at Milwaukee indicate this same condition. At Cleveland no nitrate determinations are given.

The Urbana results are those obtained from small fill and draw units in tests made primarily to determine the efficiency of various types of air diffusers. They are interesting particularly as they show a complete removal of ammonia nitrogen with the production of an almost equivalent amount of nitrates.

It is believed that the Sherman results are representative of the poorer effluents which may be temporarily obtained from activated sludge plants in small places where the operation is in the hands of an untrained man. Under similar circumstances and with a similar raw sewage, it is doubtful whether any other type of plant could produce a consistently better effluent.

SLUDGE.

The capacity of the activated sludge process to produce with reasonable expense a clear liquid effluent of almost any desired degree of stability is no longer questioned, except where the sewage contains disinfecting industrial wastes. Unfortunately it is not possible to stop at that point. In the process, large volumes of sludge are produced as a by-product. An economically practical treatment of this sludge to the point of disposal has not yet been assured.

Because it is so dilute and of a character to resist the removal of water by known methods it presents the big unsolved problem of the process. However, its relatively high nitrogen content, as compared with sludges from other processes, has directed investigation largely toward the recovery of this nitrogen for fertilizer purposes. Several methods of dewatering the sludge have been investigated, but the cost has always been nearly equal to the theoretical value of the nitrogen recovered. So far no plant has produced a sufficient quantity of dried sludge to demonstrate that it can be marketed on a large scale.

Volume.—The volume of sludge it is necessary to dispose of is largely dependent on the design and operation of the plant, with temperature conditions also a factor. Assuming that with proper sedimentation and adequate aeration 15,000 gallons of 98 per cent sludge have to be disposed of, a change in the concentration of the sludge to 99.5 per cent water, due to underaeration, inadequate settling capacity or cold weather, would increase the volume to about 68,000 gallons.

The following table contains the opinions of various investigators of the amount and concentration of sludge they feel must be taken care of in disposal operations. Some of the figures are the quantitative results of actual measured test, while others are general conclusions or design figures.

TABLE No. 56.—*Sludge to be disposed of in the activated sludge process.*

City.	Authority.	Date.	Gallons of sludge to be wasted per million gallons sewage.	Per cent water in sludge.	Pounds dry solids per million gallons.
Milwaukee (18)	Hatton and Copeland	1920	12,100	97.5	1,800
Cleveland (14)	Pratt and Gascoigne	1916	6,200	97.5–98.0	1,300
Worcester, Mass. (10)	Gault	1919	13,200	98	....
Nominal average (22)	Eddy	1920	10,000	98	....
Manchester, England (27)	Ardern	1921	23,200–35,300	99.4–99.6	....
Chicago Stock Yards (16)	Pearse	1921	41,000–47,000	99.2+	1,900–2,400

At the time of the survey, sludge at both of the Houston plants had been lagooned, and it was impossible to arrive at more than a crude estimate of the actual production. As removed from the reaeration tank it had a moisture content of 99 to 99½ per cent.

The volume as given in the above table for Cleveland was arrived at by computation from suspended matter removed, allowing 35 per cent for liquefaction. This percentage was based on observations and analyses.

From available data it appears that under favorable conditions from 10,000 to 30,000 gallons of 97.5 to 99 per cent sludge per million gallons will have to be disposed of. There is, however, relatively little data upon which to base any definite conclusions.

Treatment.—Many different methods have been tested to secure a satisfactory method for disposal of sludge.

Drying on beds has been practically abandoned for large cities, both because of the large area required and because by this method the full value of the sludge as a fertilizer is not obtained. Pratt and Gascoigne at Cleveland (14) concluded that "unless the unit quantities of sludge produced are materially lessened, the use of sand beds for dewatering activated sludge is financially prohibitive." Gault (10) at Worcester, Mass., stated that for local conditions "air drying of activated sludge as a means of disposal on a large scale has been demonstrated to be impracticable; air drying during the winter season is impossible." These statements are expressive of general opinion of the applicability of this method of drying to large installations. For smaller installations where the total volume of sludge produced can not warrant recovery processes and where land is readily available this method is applicable.

Lagooning is another method possible at smaller and medium size plants. At both the plants at Houston all sludge had been lagooned, up to the time of the survey, except a small amount used for tests. At the north side plant the sludge from 8-10 m. g. d. of sewage is to be treated in a pressing and drying plant which is already installed. It is expected that lagooning will be continued at the south side plant, which is now treating about 1½ m. g. d. At this plant a lagoon 300 by 100 by 10 feet was used for two years and is only half filled.

To make large installations of the activated sludge process economically feasible it is pretty well agreed that the nitrogen of the sludge must be recovered, and that the value of the sludge must be at least equal to the cost of the recovery process.

The processes now receiving most favorable attention are: (1) Concentration by sedimentation; (2) pressing; (3) centrifuging; (4) acidification in connection with pressing and centrifuging; and (5) drying by mechanical driers.

If the sludge is removed from the sedimentation tanks or reaeration tanks of the sewage treatment plant containing more than 99 per cent water, it can, if the sludge is good, be resettled to a water content of 97.5 or 98 per cent. The reduction from 99 to 98 per cent for instance reduces the volume to be handled to half the original volume. Where sludge can be taken from the sewage treatment tanks with a water content of 98 per cent it is doubtful whether resettling is advisable. The settling period should not exceed six hours or the sludge is likely to become septic and in this condition is much more difficult to handle.

The 98 per cent sludge then passes to the presses or centrifugal machines. Under favorable conditions the water content is here reduced to about 80 to 85 per cent. The Simplex presses installed at Houston are guaranteed by the manufacturer to produce a specified amount of 80 per cent cake daily.

As preliminary to pressing or centrifuging, acid (about 0.12 per cent of the volume of the sludge, if sulphuric acid is used) is sometimes added to the sludge to counteract to a certain extent its natural slimy characteristics, and thus put it into better condition for treatment.

From the presses or centrifugal machine the 80 (plus or minus) per cent sludge is taken to heat driers. Both the direct and indirect heat types have been tested and found to be satisfactory. These produce a sludge with 10 per cent moisture, which is screened, the larger pieces being ground and sold as a low-grade fertilizer or as a filler for a higher grade fertilizer.

The actual tests made with presses, centrifugal machines, and driers have been very extensive, and while results have demonstrated possibilities and given promise of ultimate success, there has not as yet been developed apparatus which is generally acceptable to engineers.

At Milwaukee tests are still in progress, and the design for the Des Plaines River plant (9) includes both a press and a centrifugal machine. At neither place have the exact make or type of apparatus been definitely settled. The expectations are that sludge of about 98 per cent water acidulated with sulphuric acid, using 2 to 4.5 c. c. per gallon of sludge, can be successfully and economically pressed to a cake containing about 80 (75 to 85) per cent water. The Simplex presses installed at the north side plant at Houston are accepted subject to the maker's guaranty that the two 120-plate presses will, with 98 per cent sludge, produce 54,000 pounds daily of 80 per cent cake. It is planned to add 0.65 gallon of 66 Baumé sulphuric acid per 1,000 gallons of sludge. As the Simplex press was tested at Milwaukee, this guaranty is doubtless based on results obtained there. With this press a cake averaging ¾ to 1¼ inches thick and containing 80 per cent moisture was produced from 97.5 per cent sludge in 4.5 hours at a rate of 3 pounds of cake per square foot of filter cloth.

The Berrigan press made by the Worthington Corporation produced from the same sludge at Milwaukee (18) 2.89 pounds of 81.5 per cent cake per square foot of filter cake in 4.85 hours.

At the stockyards at Chicago (16) the Simplex press, the same machine used at Milwaukee, produced from 98.6 per cent sludge with 2½ hours net pressing time a 77.9 per cent cake at a rate of 4.5 pounds per square foot of filter. A 1-inch cake was considered the most practical.

Here also tests were made with acidulated sludge, using 1.5 to 2.0 c. c. of 60 Baumé sulphuric acid per gallon of sludge. With this treatment the results were much better. Parallel tests with plain and acidulated sludge gave comparative results given in the following table:

TABLE No. 57.—*Sludge pressing at the Chicago stockyards with and without acid* (16).

	Net pressing time (hours).	Per cent water at start.	Per cent water of cake.	Pounds of cake.	Pounds cake per square foot filter.	Pounds dry solids.
Without acid	3.5	98.66	82.5	114	6.0	20.0
With acid[1]	3.5	98.57	75.7	114	6.0	27.7
Without acid	4.0	98.91	82.1	111	5.8	19.9
With acid[1]	2.15	98.83	78.6	109	5.7	23.3

[1] 2 c. c. 60 Baumé sulphuric acid per gallon sludge.

Allowing for the full cycle of filling, pressing, dumping, and cleaning, it was concluded that the yield with acidified sludge is from 40 to 100 per cent greater, in terms of dry solids, than the unacidified sludge. In general the report of the stockyard tests (16) gives the following as advantages and disadvantages of acidification:

Advantages:

1. The yield and capacity of press are increased.
2. The nitrogen and fat content of the sludge are increased.
3. The filter cloths do not clog as rapidly.
4. The sludge cake does not become septic.

Disadvantages:

1. The cost of the acid.
2. The addition of another step in the process, as well as the requirement of more equipment.

Eddy (22), assuming 15,000 gallons of 98 per cent sludge per million gallons of sewage with 6 per cent ammonia on dry basis, and estimating sulphuric acid at 1 cent per pound and ammonia at $4 per unit, gives a theoretical increase in value of the sludge due to acidification of $3.62 per million gallons with an acid cost of $2.70. This makes no allowance for losses but gives no credit to the operating value of conditioning the sludge for more economical pressing.

Data on experiments with centrifugal machines are very meager. The Shafer-ter-Meer and Besco-ter-Meer machines have both been subjected to more or less investigation, especially at Milwaukee. With the latter cakes of 80 to 85 per cent moistures have been obtained but the effluent contains much suspended matter which has been extremely difficult to remove. The authors are not aware of any permanent operating plant using centrifugal machines for sludge treatment.

In order to market the sludge the moisture must be reduced to 10 per cent. This can be accomplished only by drying with heat.

Standard makes of driers, both direct and indirect heat types, have been tested, and it is well demonstrated that no unusual difficulties are encountered.

The Milwaukee tests (18) have been conducted with a Buckeye direct-indirect drier 16 feet long and 23 inches in diameter. With this, 82 per cent sludge has been dried to bone dryness with no loss of nitrogen.

The installation at Houston, Tex., has one Buckeye direct-indirect drier, 40 feet long and 60 inches in diameter, to handle sludge from a 10 m. g. d. activated sludge plant. The makers guarantee the evaporation of 10 pounds of water per pound of 13,500 B. t. u. fuel.

Hatton at Milwaukee (18) reports that "two reputable manufacturers of driers have submitted to us full plans and propositions for driers in which they guarantee to reduce the moisture from the sludge at the rate of 10 pounds of water evaporated per pound of combustible."

COSTS.

Cost data of the activated sludge process including the disposal of the sludge can hardly be considered to be beyond the estimating stage. Costs based upon experimental results, even if the tests be of fairly large magnitude, may differ greatly from those obtained in actual practice. Labor, depreciation of the installation, repairs, and general maintenance costs must be secured for a period of years under normal operating conditions. It is not believed that possession of such data can be claimed at any place.

Cost data are, moreover, most valuable when available for comparison, e. g., to compare the installation cost and operating costs of the activated sludge with other processes, such as Imhoff tanks and trickling filters. Most of the installation costs of activated sludge plants were incurred during the period of high war prices and are, therefore, directly comparable only with other plants constructed during the same period. Accurate comparative operating costs are also difficult to secure, as interest on investment and depreciation are seldom included in issued statements.

Installation costs.—With the exception of the two plants at Houston there are no actual construction cost data obtainable for installations in this country of plants with a million gallons daily capacity. Dalhyn (5) reports one in Canada, Woodstock. The costs of a number of installations have been estimated and actual costs are available for some of the smaller plants. The table following contains cost data available from some plants in this country together with a few foreign and Canadian plants.

TABLE No. 58.—*Installation costs of some activated sludge plants.*

Plant.	Date.	Capacity m. g. d.	Cost per m. g. d. capacity.	Sludge drying plant included	Remarks.
Houston, (north side) (7)	1919	[1]10.0	[3]25,500	No.	Sludge drying plant; cost $85,000.
Houston, (south side) (7)	1919	[2]5.0	[3]25,000	No.	
San Marcos (7)	1916	[1].2	[3]25,000	No.	Septic tank, estimated at $1,500; could treat greater flow.
Sherman (7)	1919	[1]1.5	[3, 4]26,700	No.	Plant only partly completed; estimate balance to complete, $5,000.
Milwaukee (28)	1920	[2][illegible]	[4]59,000	Yes.	Include recovery of 17 acres of land from lake, pile foundations for all structure and provisions for extension.
Chicago (29)	1917	[1][illegible]	[4]65,000	Yes.	For stock yard wastes.
Fitchburg (30)	1916	[1]5.5	[4]57,000	(?)	
Bloomington, Ill. (31)	1920	[1]5.0	[4]108,000	(?)	Designed for 30,000 population.
Woodstock, Ontario, Canada (32).	1920	[1]1.8	[3]32,200	No.	
Worcester, England (33)	1919	[1]1.8	[4]15,000	(?)	
Escanaba, Mich. (34)	1917	[1]1.5	27,000	Yes.	Contract costs.
Los Angeles, Calif. (35)	1921	....	[4]60,000	(?)	Estimate by Fuller, Whipple, Mulholland.

[1] Rated. [2] Present operating. [3] Actual. [4] Estimated.

Local conditions and date of construction are items of the greatest importance. At Milwaukee where land must be made and pile foundations are necessary for all structures, the cost is naturally increased. The cost of plants built or estimated while high war prices prevailed are not comparable with costs during normal times. Moreover, costs or estimates at some places include items such as long outfall or intercepting sewers which do not affect the installation costs of the treatment plant proper.

The cost figures in the above table may be roughly divided into four groups. First the foreign plant at Worcester, England, estimated at $15,000 per million gallons; second, six plants averaging $26,900 per million gallons, in every one of which the costs are practically actual construction costs; third, four plants averaging $60,000 per million gallons all of which are estimates; and fourth, the plant at Bloomington, Ill., estimated at $108,000 per million gallons. It has not been possible to secure figures in sufficient detail to account for the differences between these groups. Local conditions may necessitate much more expensive work at one place than at another, and the fluctuations of material and labor prices during the past few years have covered such a wide range that unit costs are essential for satisfactory comparisons.

In comparison with plants including Imhoff tanks, trickling filters, and secondary sedimentation tanks, the activated sludge plant requires a lower initial investment in construction. Eddy (30) in 1916 prepared comparative estimates for a 5.5 m. g. d. plant at Fitchburg, Mass., the Imhoff filter plant being $431,000 and the activated sludge $314,000. The Imhoff filter plant when actually built in 1914–15 cost $350,800.

Pearse (31) gives comparative estimates for a plant at Bloomington, Ill., as $650,000 and $540,000 for the Imhoff filter plant and activated sludge processes, respectively. The plant was to serve a future population of 50,000.

Goddard and Ehlers (36) estimated that in general the initial costs of activated sludge plant are approximately half of a screen-sedimentation filtration disinfection plant.

Operating costs.—Operating costs including maintenance and depreciation are very meager and for the most part estimates based upon experimental data. Many of the estimates should, however, work out in practice as they are based upon experiments conducted on a scale almost comparable with actual operating conditions.

In plants where the sludge is not dried for fertilizer the gross cost and net cost of operation are the same. Where, however, sludge recovery is practiced the net cost becomes the gross cost less the profit on the sludge. In such plants the net cost is the cost of treating the sewage including interest, maintenance, and depreciation of the treatment plant, plus the cost of drying and marketing the sludge, also including the usual items of interest, etc., less the market value of the sludge.

These figures, except in a very few cases, are not available, but it appears that with a plant operating near capacity and recovering the sludge the net operating cost will be from $15 to $20 per million gallons.

At Houston the operating cost, exclusive of interest and depreciation were, for the year 1919, $14.70 and $21.20 for the north and south side plants, respectively. At both plants the sludge was lagooned. The details of the items entering these totals are given on page 85. Neither of the Houston plants were operating at full capacity, but their total expenses for supervision were about the same as if they had been. If the data given in this table be used with the operating capacities of the plants, and if these capacities be taken as 8 and 4 m. g. d. for the north and south side plants, respectively (they were designed for 10 and 5 m. g. d.), the operating costs can be computed to $13.48 and $13.50 per m. g. d. The power costs and supplies in this computation are assumed to remain the same, but the cost for chief operator, operators, laborer and chemist are assumed to be the same per m. g. d. treated in total, regardless of the volume treated. Estimating interest and depreciation at 10 per cent of the construction cost these gross figures would become $22.30 and $21.50. If at the north-side plant the recovered sludge yields a net profit of $3.50 per million gallons the net cost becomes about $19.

At Milwaukee Hatton (28) estimated a net cost of $15.58. The operating cost, including sludge drying, is estimated at $33.58, of which $14.07 is capital charge and $19.51 operating costs. The sludge is estimated to be worth $18 per m. g. on a basis of 1 ton of 4.5 per cent nitrogen, 10 per cent moisture, sludge per million gallons with nitrogen at $4 per unit. This estimate was later revised (31) to give a net cost of $17 per million gallons, with treatment and sludge drying costing a total of $35, from which the value of the sludge, $18, is deducted.

The San Marcos plant was operating in 1919 at a cost of about $14.50 per m. g., exclusive of interest and depreciation. Allowing 10 per cent of the plant cost as annual charge for these items, the total operating cost would be about $21. At this plant sludge can not be considered either an asset or liability. It is not recovered but costs very little to dispose of, because of available ground adjacent to the plant on which it can be applied.

No fair estimate of the costs of the Sherman plant is possible. Only half the plant is in use; but the construction costs can not be divided, as the unused half has never been completely finished. The half in use is not operating at capacity, and there is little control over the amount of air used.

The plant as operating is costing for operation alone, exclusive of interest and depreciation, about $28 per million gallons treated. One operator at $100 per month is charged entirely to the sewage plant, although he gives probably half of his time to a small incinerator in which the city's garbage is burned. Power is estimated at $2,000 per annum on the basis of a 22-horsepower motor under full load with current at 1½ cents per kilowatt hour. A 10-horsepower motor would probably be ample with the present flow.

It is probable that with the plant operating at capacity the costs would not be far from those figures already given for the other plants, probably about $20 per million gallons.

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(34) Activated Sludge Process of Sewage Disposal Firmly Established. T. C. Hatton. Engineering Record, vol. 75, p. 16-19.

(35) Findings of Los Angeles Sewage Disposal Commission. Summary of report by George W. Fuller, George C. Whipple, and William Mulholland. Engineering News-Record, vol. 86, p. 1117-8.

(36) Bureau of Sanitary Engineering. Municipal Sanitation. Texas State Board of Health, publication No. 3. C. W. Goddard and V. M. Ehlers.

FINE SCREENING.

"There is no agreement among engineers as to the size of the opening which is on the boundary between coarse and fine screening. In a general way the tendency of the present time seems to be to regard an opening of one-fourth inch as the maximum limit for fine screening."[8] Screens of this type were found only at Baltimore, Md., the Irondequoit plant at Rochester, N. Y., and San Marcos, Tex. All of these screens have been described in detail under these plants, and reference is made to these descriptions.

The function of fine screens is confined to the removal of solids. They have been used for this purpose in three ways: First, as a complete treatment for the removal of the larger and especially the floating solids at places where there are adequate dilution facilities to dispose of sewage by this method, the screens serving to prevent surface nuisances. Second, as preliminary to tank treatment for the removal of the large and nonsettleable solids. This is the situation at the Irondequoit plant at Rochester, and it is for this purpose that screens are recommended as preliminary to treatment in the aeration tanks of the activated sludge process. Third, as a protection for nozzles on trickling filters to remove solids carried over from sedimentation tanks which are capable of clogging the nozzles. The screens are used for this purpose at Baltimore, Md., and have effected a reduction of about 87 per cent in the number of nozzles cleaned.

At only one plant, the Irondequoit plant at Rochester, were analytical determinations made of the influent and effluent of the screens. These results are given in detail under the discussion of this plant. The following table gives the averages of the suspended matter results for the various size screens and, for comparison, the results obtained with fine screens of the same and other types at one or two other places.

TABLE No. 59.—*Main structural features and results obtained with some fine screens.*

Plant.	Type of screen.	Size of opening.	Suspended matter, p. p. m.			Per cent removal based on screenings removed.
			Influent.	Effluent.	Per cent removal.	
Rochester, N. Y. (Irondequoit) a	Riensch-Wurl	1/16 by 2 inches	200	196	+2	2
Do.	do	1/8 by 2 inches	211	222	−5	
Do.	do	1/4 by 2 inches	120	156	−30	
North Plainfield, b Plainfield and Dunellen, N. J.	do	1/16 by 2 inches	c 140	c 156	−12	d [illegible]
Cleveland, Ohio e	Drum	30-mesh	346	270	22	28
Do. e	do	60-mesh	342	272	20	23
Do. e	do	120-mesh	312	256	18	24
Brockton, Mass. f	do	30-mesh	963	290	71	....

a Survey results.

b Operating Data of Fine Screens and Imhoff Tanks. John R. Downes, Public Works, vol. 50, pp. 370-371.

c Influent is average of 3 years 1917-1919, inclusive, during which time a yearly average varied from 140-160. Effluent is average for year 1920.

d Estimated.

e Report on Tests at Sewage Testing Station, Cleveland, Ohio. Robert Hoffman, R. Winthrop Pratt, Harry B. Hommon, 1914, p. 60.

f The Clarification of Sewage by Fine Screens, Kenneth Allen, Proceedings Am. Soc. C. E., Vol. XL, No. 6, pp. 1630-1669.

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[8] American Sewerage Practice, Metcalf and Eddy. Vol. III, p. 310.

Of the four results from Riensch-Wurl screens, only one showed any removal based upon the suspended matter results of the raw and screened sewage, the other three results giving higher suspended matter in the screened than in the raw sample.

The reason for this condition has been discussed under the suspended matter determination, where it was shown that the suspended matter results for the raw sewage at Rochester were not accurate closer than 9 per cent. The difficulty of securing representative samples of sewage containing large pieces of suspended solids prevent accuracy within the limits of efficiency, unless the efficiencies are greater than 10 to 15 per cent.

As based upon the screenings removed the average efficiency of the Riensch-Wurl screens at Rochester was 2 per cent and of that at Plainfield 8 per cent.

The drum screens covered with a fine mesh wire cloth give higher removals amounting to 20 to 30 per cent at the Cleveland testing station, and 71 per cent at Brockton, Mass. In this latter case the high removal is due largely to the extreme concentration of the raw sewage, the effluent from the screens here containing more suspended solids than any of the others listed in the above table.

The rates attainable on the Riensch-Wurl screens at Rochester, which have a diameter of 12 feet, have been determined by N. A. Brown, special assistant engineer, to be from 16 to 40 m. g. d. with a loss of head of 0.4 to 1 foot, respectively, for the one-eighth-inch slot, and from 16 to 35 m. g. d. with a loss of head of 1.2 to 1.7 feet, respectively, for the one-sixteenth-inch slot.

The use of fine screens in this country has been largely restricted to the removal of the larger solids likely to produce visible surface pollution when sewage is disposed of by dilution. The results at Rochester would indicate that they are not of any great value as preliminary treatment before sedimentation in tanks. As an intermediate treatment between tank and trickling filters, Baltimore has found the screens useful, but when installed at Atlanta for this purpose they were found to be unnecessary and their use was discontinued. Relative to the screens at Brockton, which preceded Imhoff tanks, Downes[9] states:

> It is interesting to note that, outside of interest charges, the comparative costs as between screening and removing the objectionable solids from the tanks by hand are just about equal; that is to say, the time now spent by a watchman on the screen and the cost of power about equal the cost of labor in removing the coarse solids. The plant, however, is much more workable and the nature of the labor much less objectionable when the solids are removed before reaching the tanks.

As discussed under activated sludge the use of fine screens as a preliminary device ahead of the aeration tanks has been recommended, and as this process develops the fine screens may be accepted as essential.

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[9] See note 2, Table No. 59.

The general attitude toward fine screens among the engineers of this country has not become crystallized. Allen [10] stated in 1914:

> The use of fine screens for sewage deserves more serious consideration than it has received heretofore in America. * * * it is the writer's opinion that fine screening will be adopted in the future by many towns situated on bodies of water which are capable of assimilating the effluent; possibly, also, as a preliminary process to tank treatment, filtration, and disinfection. On the other hand, the relatively high cost of attendance and the probable lack of market for screenings, when compared with conditions abroad, will probably serve to prevent the marked increase in their use in the United States which has been experienced in Germany.

Fuller, in his "Sewage Disposal," published in 1912, states: "Screens have a far greater field for usefulness than is generally recognized in America." But in his report to the Metropolitan Sewerage Commission of New York, in 1913, he stated that he preferred fine screens to sedimentation tanks only where it was advisable or necessary to remove only relatively large sewage matters in suspension.

Metcalf and Eddy [11] on the other hand are less optimistic, saying:

> It seems probable that the day of elaborate fine screening has passed, in view of the results attained with improved sedimentation tanks. If the matter removed by fine screening can be successfully taken out in sedimentation basins, the cost will usually be less.

They also refer to the opinions and experiences of Hering, Pearse, and others, which tend to discourage the use of fine screens in connection with sedimentation tanks, and to restrict the field to plants where the removal of large solids is sufficient treatment before disposal by dilution.

SLUDGE.

Sludge is the principal by-product of sewage treatment. It consists of the solids, other than screenings, removed from the sewage by the treatment processes. As the removal of these solids is one of two functions of a treament plant, the ultimate disposal of sludge is a necessary part of the operation of any plant.

Sludges from different treatment processes vary greatly in the volume produced and in physical characteristics and chemical composition.

Volume.—The amount of sludge produced per million gallons of sewage treated depends not only upon the treatment process and device employed, but upon the character of the sewage treated. While no average values can be given for the quantities produced by different processes, there are, with the same sewage, general tendencies which are typical of the processes. Thus, Imhoff tanks produce a relatively low moisture content, well digested sludge; activated sludge produces the largest volume with the highest moisture content; and chemical precipitation produces the largest amount of dry solids.

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[10] See note 6, Table No. 59.

[11] American Sewage Practice, Metcalf and Eddy. Vol. III, p. 352.

In a general comparison, Eddy[12] has used the following table:

TABLE No. 60.—*Nominal volume of sludge produced by different processes of sewage treatment.*

Treatment process.	Normal volume of sludge per million gallons of sewage treated (gallons).	Proportion of solids in sludge.	Specific gravity of sludge.	Weight of dry solids in sludge per million gallons of sewage treated (pounds).
Activated sludge	10,000	2.00	1.005	1,675
Chemical precipitation	5,000	7.50	1.040	3,250
Sedimentation	2,500	5.00	1.020	1,060
Septic tank	500	5.00	1.040	220
Imhoff tank	500	15.00	1.070	670
Trickling filter-humus tank	500	7.50	1.025	320

Judging by the information obtainable at the plants surveyed, records of sludge production are not as a rule kept. Of the 12 cities visited, 5 or 6 had information on this phase of operation, and 2 or 3 others kept records of the amount of sludge removed from beds, but had no determinations of moisture by which it would be possible to approximate the volume deposited in the tanks. The following table contains the local data which were obtained:

TABLE No. 61.—*Volume of sludge deposited per million gallons of sewage treated.*

City.	Year for which record is given.	Volume of sludge deposited per million gallons (cubic yards).	Per cent water.	Specific gravity.
Baltimore, Md., hydrolytic tanks	....	5.95	91.6	1.02
Columbus, Ohio, Imhoff tanks	1920	3.06	....	....
Fitchburg, Mass., Imhoff tanks	1919	4.45	87.9	1.04
Fitchburg, Mass., secondary sedimentation tanks	1919	1.31	93.9	1.02
Reading, Pa., septic tank	1918	2.62	....	....
Reading, Pa., average of 4 secondary sedimentation tanks	1918	4.66	....	....
Rochester, N. Y. (Brighton), Imhoff tank	1918	1.30	83.6	....
Rochester, N. Y. (Brighton), secondary sedimentation tanks	1918	.97	87.8	....
Rochester, N. Y. (Irondequoit), Imhoff tanks	1919	1.38	79.0	....

At Alliance, Ohio, a record was kept of the sludge beds cleaned, from which an approximate volume of bed dried sludge was obtainable; but as no moisture determinations were made, the volume of sludge as deposited in the tanks was not computable.

Canton, Ohio, stopped measuring sludge removal in 1918 when it became necessary to supplement the sludge beds by lagoons and broadcast application to fields.

The records at Atlanta had suffered by the absence of the regular plant operator, who entered the Army in the fall of 1917 and returned to the plant only a week before this survey was made.

At Houston, Tex., and Lexington, Ky., only approximate estimates were possible. These were not included in the above table, as it was not felt that they are sufficiently accurate. No records of any sort were kept at San Marcos or Sherman.

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[12] Lights and Shadows of the Activated Sludge Process. H. P. Eddy, Public Works, vol. 51, pp. 112-115, 130-133.

Analyses of sludge.—With the exception of Sherman, Tex., samples of sludge were taken at all the plants surveyed, and analyzed. The moisture and specific gravity determinations were, of course, made at the plants, and the dried samples were then shipped to the office at Cincinnati, Ohio, and the other determination made after the entire survey was completed.

The value of the fertilizing ingredients, especially the nitrogen, is at present one of the important subjects in sewage treatment because of the development of the activated sludge process whereby sludge is produced sufficiently high in nitrogen to bring its recovery within the limits of economic possibilities.

For this reason it was considered advisable to include with the analyses made on the survey those of sludges at other cities. These are contained in the following table which is arranged to group sludges from different devices or processes together:

TABLE No. 62.—*Sludge analyses.*

City.	Notations.	Specific gravity.	Per cent water.	Per cent volatile matter.	Per cent dry basis.			
					Total nitrogen.	Phosphates as P_2O_5.	Potassium as K_2O.	Ether soluble matter.
From septic tanks:								
Worcester, Mass.	(1)	....	....	43.9	3.01	....	....	....
Columbus, Ohio[1]	(1)	1.081	83.4	26.8	1.34	....	....	6.8
Cleveland, Ohio	(2)	1.038	89.2	40.8	1.50	1.2	....	9.0
Reading, Pa.	(1)	....	91.8	47.0	....	....	....	....
Philadelphia, Pa.[2]	(1)	1.046	86.9	49.0	1.35	....	....	7.3
Waterbury, Conn.[3]	(1)	1.025	85.8	45.5	1.35	....	....	10.8
Akron, Ohio	(15)	1.07	84.0	41.5	.96	....	....	6.6
Baltimore, Md.[3]	(9)	....	79.2	72.8	2.64	....	....	9.0
From Imhoff tanks:								
Worcester, Mass.	(1)	....	....	49.1	2.63	....	....	....
Philadelphia, Pa.	(1)	1.035	82.5	38.0	1.2	....	....	6.5
Cleveland, Ohio	(2)	1.057	85.3	34.0	1.2	....	....	8.3
Columbus, Ohio	(14)	.997	96.2	....	2.8	1.6	.6	24.4
Alliance, Ohio	(14)	1.012	78.4	52.1	2.5	1.9	.4	8.5
Atlanta, Ga. (Peachtree)	(14)	1.016	92.2	47.3	2.3	1.6	.5	13.2
Atlanta, Ga. (Intrenchment)[4]	(8)	1.02	87.0	39.1	1.25	....	....	6.1
Baltimore, Md.	(14)	.992	94.2	67.7	3.6	.8	.2	20.6
Do.	(9)	1.017	92.3	62.7	.75	.58	.19	....
Fitchburg, Mass.	(14)	1.034	88.7	70.4	2.0	1.6	.6	7.7
Lexington, Ky.	(14)	1.014	92.0	51.7	3.0	2.0	.5	9.2
Canton, Ohio	(14)	.990	86.5	37.5	1.6	1.2	.2	12.6
Rochester, N. Y. (Brighton)	(14)	1.015	85.5	32.3	1.9	.8	.2	6.0
Rochester, N. Y. (Irondequoit)	(14)	1.031	87.4	47.0	2.2	.8	.6	8.0
Eight cities[5]	(6)	....	....	36.1	1.61	1.15	....	....
Akron, Ohio	(15)	1.11	75.0	48.4	.80	....	....	6.2
From activated sludge process:								
Houston, Tex.	(12)(14)	....	....	44.7	3.0	2.1	.4	5.0
Do.	(13)(14)	....	....	46.0	3.1	2.2	.4	5.4
Cleveland, Ohio[6]	(4)	....	97.5+	49.0	3.21	1.73	.29	6.77
Milwaukee, Wis.[7]	(5)	....	99.3	67.5	4.5	2.0	....	5.4
Do.[8]	(5)	....	10.5	82.5	5.1	1.5	....	5.3
Sherman, Tex.	(14)	....	....	76.6	5.8	2.8	.6	10.4
Urbana, Ill.	....	....	....	....	....	....	....	....
Syracuse, N. Y.	(8)	....	....	....	5.1	....	....	17.7
Worcester, Mass.[9]	(10)	....	....	....	4.06	2.26	....	....
Garbage tankage:								
Los Angeles, Calif.	(7)	....	....	....	3.05	1.96	1.22	1.71
Cleveland, Ohio	....	....	....	....	3.1	4.0	....	....
Horse manure	(11)	....	....	....	1.7	.26	1.5	....

[1] Average of 5 analyses.

[2] Average of 2 analyses.

[3] From hydrolytic tank.

[4] Average of 36 analyses.

[5] Average of analyses of air-dried sludge from 8 cities.

[6] Average of 18 to 20 analyses; only 3 for potassium.

[7] From sedimentation tank.

[8] Dried press cake.

[9] Average of 4 analyses.

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FIG. 33.—FARMERS TAKING SLUDGE AT ALLIANCE, OHIO

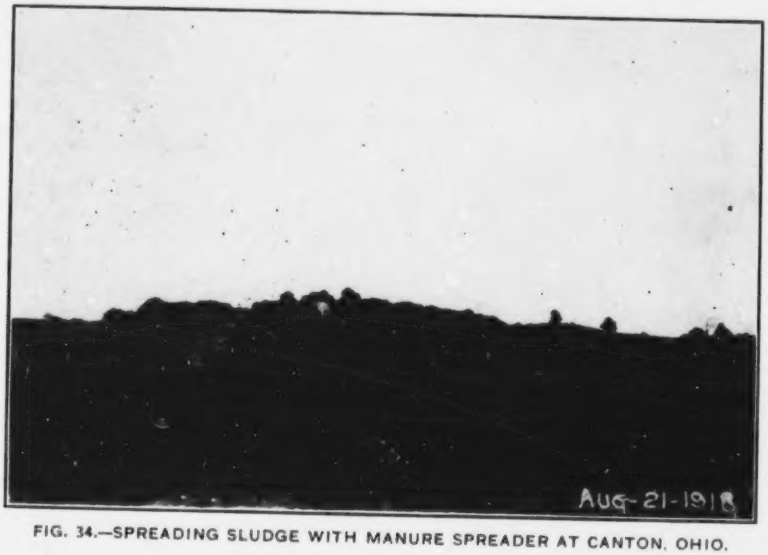

FIG. 34.—SPREADING SLUDGE WITH MANURE SPREADER AT CANTON, OHIO.

References for Table No. 62.

(1) American Sewerage Practice, Metcalf and Eddy. Vol. III, pp. 470–471.
(2) Report on Tests at Sewage Testing Station, Cleveland, Ohio, 1914. Robert Hoffman, R. Winthrop Pratt, Harry B. Hommon.
(3) Experience and Results of Four Years' Operation of Coarse Screens, Grit Chambers, Imhoff Tanks, and Trickling Filters at Atlanta, Ga. Charles C. Hommon. Paper read at 23d Annual Convention of American Society of Municipal Improvements, October, 1913.
(4) Activated Sludge Results at Cleveland. R. W. Pratt and G. B. Gascoigne. Engineering News, vol. 76, pp. 1061–1066, 1124–1128.
(5) Third Annual Report Milwaukee Sewerage Commission.
(6) The Fertilizer Value of Activated Sludge. W. D. Hatfield, Illinois State Water Survey, Bulletin No. 16, p. 101.
(7) Garbage and Rubbish Disposal in Los Angeles, Calif. S. C. Simons. Engineering News, vol. 76, p. 679.
(8) Economic Values in Sewage Sludge. R. Wells. Proceedings American Society Municipal Improvements, vol. 26, pp. 55–97.
(9) Nine Years' Operation of the Baltimore Sewage Works. T. C. Schaetzle. Engineering News-Record, vol. 87, p. 98.
(10) Annual Report Superintendent of Sewers, 1919.
(11) Bulletin 246, Ohio Agricultural Experiment Station.
(12) From drier.
(13) From dust room.
(14) Survey results.
(15) Report on Sewage Testing Station, Akron, Ohio, 1912. Harry B. Hommon.

It is noted that the specific gravities of three of the sludges analyzed on the survey are less than 1.0. These samples contained at the time of analysis large numbers of minute gas bubbles which could not be removed. The analyses were made on freshly drawn samples and the results were checked.

While there is more or less variation in sludges produced by the same process from different sewages, the one outstanding difference in the above table lies in the nitrogen contents of sludge from the activated sludge process as compared with other sludges, the former averaging 4.2 per cent or more and the latter 2.1 per cent.

With acid treatment the nitrogen in activated sludge has been further increased. Eddy [13] estimates this increase to average 12 per cent. He also states that since in pressing solids low in nitrogen are lost with the press liquor there is an apparent nitrogen increase in pressed sludge, which he estimates at 9 per cent.

After ignition for the determination of volatile matter the residual ash was analyzed. The results of these analyses are contained in the following table. For the sake of completeness the phosphates and potash already recorded in Table No. 62 are repeated here.

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[13] Loc. cit. p. 171.

TABLE No. 63.—*Mineral analyses of the ash from sludges obtained on the survey.*

City.	Type of tank.	Results in per cent of sludge dried at 100° C.										
		SiO_2 and HCl insoluble residue.	Al_2O_3 and Fe_2O_3.	P_2O_5.	SO_3.	CaO.	MgO.	K_2O.	Na_2O.	Total by analysis.	Ash found.	Per cent error.
Alliance, Ohio	Imhoff	35.8	8.2	1.9	0.9	1.8	0.3	0.4	2.0	47.9	51.3	3.4+
Atlanta, Ga	do	26.8	18.5	1.6	1.4	2.6	.5	.5	1.7	52.7	54.9	2.2+
Baltimore, Md	do	22.6	6.4	.8	1.0	2.4	.3	.2	1.9	32.3	35.6	3.3+
Do	Digestion	17.7	3.4	1.0	2.3	1.7	.1	.5	.4	29.6	27.1	2.5−
Canton, Ohio	Imhoff	44.3	11.0	1.2	1.5	3.9	.3	.2	1.7	62.2	64.1	1.9+
Columbus, Ohio	do	22.1	4.2	1.6	2.2	4.5	.5	.6	.8	37.1	36.5	.6−
Fitchburg, Mass	do	47.8	9.0	1.6	.6	.8	.3	.6	.5	60.8	61.2	.4+
Lexington, Ky	do	31.1	6.1	2.0	1.0	5.0	.4	.8	.7	48.3	47.1	1.2−
Rochester, N. Y. (Brighton.)	do	58.1	5.2	.8	.6	2.7	.5	.2	2.0	67.7	70.1	2.4+
Rochester, N. Y. (Irondequoit.)	do	40.8	3.6	.8	1.0	2.5	.3	.6	1.2	52.4	50.8	1.6−
Average		34.7	7.6	1.3	1.2	2.9	.4	.5	1.3	49.1	49.9	.8
Houston, Tex., drier	Activated sludge	44.7	7.1	2.1	.3	1.4	.4	.4	.6	55.3	57.0	1.7+
Houston, Tex., dust	do	42.4	6.5	2.2	.3	1.3	.4	.4	.6	54.0	54.1	.1+
Sherman, Tex	do	9.3	2.9	2.8	1.0	2.5	.2	.6	3.3	23.4	22.6	.8−

Sludge as a fertilizer.—The use of sewage sludge as a fertilizer is receiving more attention now than ever before in this country, due to the production of a relatively high nitrogen sludge by the activated sludge process. There appears, however, to be some grounds to question the general tendency to disregard sludges from other processes.

The utilization of sludge may be viewed from two angles. First, the application of sludge direct to the soil either in liquid form as it comes from the tanks or in a solid form as it is taken from drying beds. This use is restricted to areas not far distant from the treatment plant. Second, the production of an article comparable in form to commercial fertilizers, and with sufficient chemical fertilizing ingredients to justify its use as a filler for high-grade fertilizers, or as a low-grade fertilizer by itself.

Up to the time activated sludge was developed the second method was practically precluded by the low nitrogen content as compared with the cost of the preparation. It is believed, however, that sufficient attention has not been given to the first method, especially where conditions can be favorably developed.

It is probable that this has been due to the fact that, for the most part, only the chemical fertilizing ingredients of the sludge have been taken into consideration, whereas the effect of the organic matter in the sludge on the texture of the soil and the fertility value of the humus formed from the sludge are factors well worthy of consideration.

Bach and Frank[14] conclude that the physical quality or character is equally as important as the content of nitrogen. Similar expressions have been made by Imhoff and others, but the general tendency has been to deprecate the value of sludge because of its low chemical fertilizing constituents.

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[14] H. Bach and L. C. Frank, Fresh Sludge and Decomposed Sludge, Eng. Record, vol. 68, p. 331.

These factors are well recognized in the case of barnyard or stall manure in which the plant food content is but little, if any, higher than in many sludges. "In general, stall manures are found to have a higher manurial value than is indicated by the amount of phosphorus, potash, and nitrogen which they contain. Through them there is introduced into the soil large quantities of humus bodies, whereby the physical state of the soil is profoundly modified and its adaptability to the growth of crops, as a rule, increased." [15]

Fowler in an article on activated sludge states, "Among other things peat has been shown to contain substances that stimulate plant growth termed auximones. These are produced by bacteria working on organic matter, rendering it available for plant life and assisting in the production of the better-known vitamines, which are an important ingredient of animal food. It is believed that the bacteria in activated sludge may produce auximones, and that it is for this reason that this material shows a superiority to other manures."[16]

Bottomley[17] in 1915 gives the name auximones to those organic substances necessary in small amounts for the growth of plants and in some respects analogous to Suziki's "orizinins," or Funk's "vitamines," but differing from vitamines in that they are not destroyed by heat. They are plant food accessories.

It is not believed that sewage sludges have ever, as yet, been tested for auximones. The possibility of their presence together with the other values inherent in sludges for plant production has not been given general attention.

Popular prejudice has also militated against the use of the sewage sludge. At one city visited a teacher of botany, while admitting the increased yield from sludge treated land, urged against its use because the "fruit" would not be "fit" to eat.

The treatment plant operator who has to dispose of his sludge after its removal from drying beds can, in many cases, develop a demand for this sludge among farmers in the vicinity of the plant. The expense of hauling sludge from the plant can be saved, and, after a time, a small charge, probably sufficient to pay for the labor of cleaning the beds can be made for the sludge.

At three plants visited on this survey, Alliance, Ohio, Canton, Ohio, and Rochester, N. Y. (Irondequoit plant), the local farmers were making extensive use of the sludge, calling for it at the plant and, at Rochester, paying a small sum for it. At Lexington, Ky., also, farmers were experimenting with the sludge in 1920 and using it in increasing amounts in 1921. Some was used at Baltimore, Md., but the bulk of the bed dried sludge at this plant was sold to a reduction company which maintained a drying plant on adjacent land.

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[15] Wiley, Principles and Practice of Agricultural Analyses, Vol. II.

[16] Digest, by Kenneth Allen of monograph by Dr. Gilbert J. Fowler, Engineering and Contracting, Aug. 25, 1921.

[17] A Bacterial Test for Plant Food Accessories (Auximones). W. B. Bottomley. Proc. Roy. Soc. London, vol. 89, p. 102.

At no place was any extensive information available from which quantitative results of the use of sludge could be determined. General opinions and experience were, however, very favorable.

At Alliance, Ohio, four farmers were interviewed. No. 1 with a clay loam soil used undigested sludge from plain sedimentation tanks for grass, corn, and wheat. He considered sludge with 75 per cent moisture as taken from the beds to be worth twice its weight of barnyard manure. When used as a top dressing, followed by lime which he uses also with manures, on wheat and clover, he had the biggest crops he had ever raised. With too heavy application the crop never heads, and only a rank growth is produced. He felt he was still getting benefit from sludge applied four years previously. However, he has not hauled any sludge the past few years as he has not had time.

No. 2 hauled bed dried digested sludge 4 miles and used it for corn, wheat, grass, and potatoes on a poor clay land known as "Lexington clay." He claimed an increased yield of about 100 per cent for the corn, wheat, and grass over similar land receiving no fertilizer. The potato crop failed because of a dry season. One field treated with sludge eight years previously is, in his opinion, still showing the benefit. In general he considers sludge to be of about the same value as barnyard manure, but harder to handle.

No. 3 has been using sludge since 1916 for wheat and corn, hauling it 2½ miles. He has used sludge only with barnyard manure followed with lime. He could give no specific results, but considered sludge slightly superior to manure, the greatest objection being the odor if the sludge is piled.

No. 4 has hauled sludge 1½ miles and used it for corn, oats, wheat, and grass (timothy). He does not think he was benefited very much in the corn yield; the oats and wheat were good, but a phosphate fertilizer was used with the sludge; the grass, however, was the best he had ever had. He uses about 10 loads per acre, the same as when using barnyard manure, spreading by hand as a top dressing, but feels that it would be better to plow it under. Given his choice he would prefer barnyard manure as giving more lasting benefit, but he considers the sludge well worth hauling.

At Baltimore the hydrolytic tank sludge from the beds went to a drying plant. Several farmers used the screenings from the coarse bar screens, but the only sludge available to them was that from the beds located by the Imhoff tanks, of which only one or two units were in operation during 1919 and 1920. The farmers remove the sludge from the beds, saving this expense, and pay in addition 25 cents per load, which may be one or two tons according to the size of the wagon or truck.

One farmer, No. 5, considered sludge "too strong," claiming that it "burned up the crops." This is fairly common experience where too much sludge is used or where the soil is particularly dry during a growing season. This farmer has had good results with beans when using sludge direct from the tanks, applying about 4,000 gallons per acre.

No. 6, the superintendent of the sludge drying plant, reported a yield of 17 bushels of potatoes from 1 bushel of seed when using heat-dried sludge. He tested eggplants, sludging 5 plants and using 5 plants as a check without any fetilizer. The 5 sludged vines yielded 40 matured eggplants, but the 5 check vines only 1 or 2 poor plants. With cucumbers, which are considered hard to raise in that section, he obtained, with sludge fertilization, yields five times as large as without fertilization. It is unfortunate that no data was kept of the amount of sludge used or that no other fertilizer was used to compare with the sludge.

No. 7, using bed-dried sludge on grass, considered it the equal of barnyard manure, reporting an increased yield due to sludge of at least two to two and one-half times that of unfertilized fields.

The farmers at Canton, Ohio, were the most enthusiastic users of sludge met during the survey. Six, including the superintendent of the sewage treatment plant, were interviewed. No. 8, the superintendent of the plant, has used sludge on the farm connected with the plant. The soil is sandy and was badly run down when taken over by the city. In 1918 sludge was applied, 6 loads per acre, to 18 acres of sandy soil, ploughed under, and the field planted in corn. There was no appreciable benefit derived that year. In 1919 sludge from the tanks was pumped onto this land, about 25 to 30 cubic yards per acre, ploughed under, and corn again planted. This year the yield was increased by an estimated 50 per cent. In 1920 this same 18 acres without any additional sludge and a 10-acre field of poor clay land treated with 20 loads of bed-dried sludge per acre was sown in oats. The yield was about 43 bushels per acre. After harvesting the oats, winter wheat was planted. In spite of frosts, which injured all wheat more or less, the yield was 25 bushels per acre as compared with an average of 15 for the vicinity. In the fall of 1919 and winter of 1920 another field planted in grass was top dressed with sludge direct from the tanks with a fire hose, a total of 1½ to 2 inches being applied. When inspected in June, 1920, the growth was so rank and heavy that it was questionable whether it would stand up to be harvested.

No. 9 considered bed-dried sludge superior to the best stable manure. He used it only as a top dressing. After having had a poor wheat crop in the fall of 1919 on land which six years previously was considered worth $40 per acre as against an average value for the locality of $100, he top dressed with sludge, using a manure spreader set at 8 loads per acre, and planted in winter wheat. The yield was 40 bushels per acre, while similar land on the same farm yielded 19½. Following the wheat with clover, he obtained a rank stand which ripened earlier than other clover, but the crop was lost by wet weather. In another field of 49 acres, 9 acres were treated with sludge in 1918, using 20½ loads per acre, and planted with mixed clover and timothy. Two crops were harvested from these 9 acres, the first, so heavy that it "went down" and was hard to cut, gave 30 tons and the second 5 tons, or a total of about 4 tons per acre. On the 40 acres not sludged a total of 42 tons was obtained. This was considered a fair crop, 1½ tons per acre being a good yield for the locality. This field after two years was considered as still being benefited by the sludge. This farmer considers from his experience that sludge is good for grasses, wheat, and corn, but "too strong" for oats, the one crop he tried it on growing so rank that it "went down" before ripening. Oats, he said, can be grown the second year after sludge treatment.

No. 10 also preferred sludge to barnyard manure. He had at the time of the survey a good stand of wheat on land to which he had applied 20 loads of sludge per acre, land which was, to start with, too "poor" to raise any crops at all. (See fig. No. 37.) With raspberries he got an estimated increase of 25 per cent. The crop was not earlier but the berries were bigger.

No. 11 considered sludge nearly as good as manure. He obtained a yield of 25 bushels of wheat per acre on land treated with 15 loads of sludge per acre, but admitted that he had always had plenty of manure and had had equally as good crops from the same field which was "good" land.

No. 12 reserved judgment on the value of sludge as compared with manure, but he gave the results of his tests as follows: Land so "thin" that his neighbors told him he would never get his seed corn back was top dressed with 22 loads per acre. The crop, however, was better than the average on reputed good land. To test the relative value of sludge and manure, he took a field of 30 acres, treating 15 acres with sludge and 15 with manure (the amounts used were not given). The sludged section, he reported, was superior to the manured section, the cattle preferring the sludged section and eating the grass closer. The poorest part of a hay field with 15 loads of sludge per acre yielded three times the crop of the untreated better section. A tract of shale clay, "too poor for grass" a few years ago, was given 18 loads of sludge and 9 loads of manure per acre. The stand of wheat in the summer of 1920 was, he claimed, the best in the vicinity.

178a

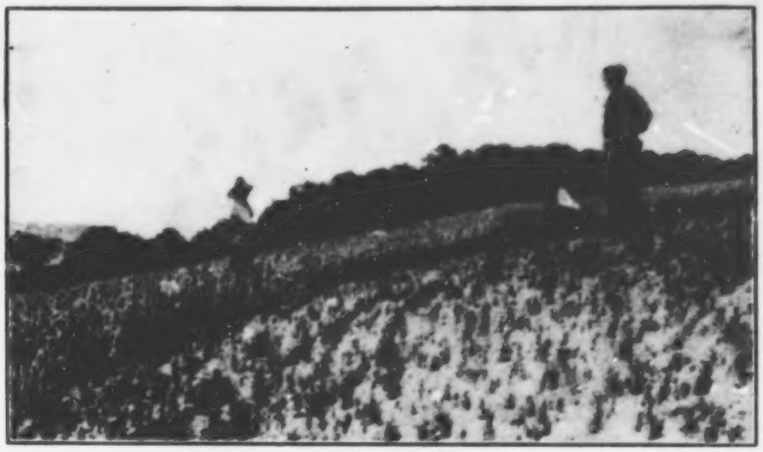

FIG. 35.—WHEAT FIELD AT CANTON, OHIO, SHOWING GROWTH ON SLUDGED AND UNSLUDGED SECTIONS.

FIG. 36.—GLASS-COVERED SLUDGE BEDS AT CANTON, OHIO.

No. 13, while not strictly a farmer, used sludge in his private vegetable garden. He was an enthusiastic advocate of sludge for all garden truck, considering it superior to barnyard manure. Nothing had been put on his land for the three years before he applied two loads of sludge to a plot 50 by 80 feet, or about 22 loads per acre. His sweet potatoes were the "best he had ever had." Irish potatoes gave an exceptional yield, beets were better than usual, onions, lettuce, cabbage, peas, beans, cauliflower, parsnips, sweet corn, cucumbers, and tomatoes were good, but he was unable to give any relative figures.

At Rochester, N. Y., the bed-dried sludge from Imhoff tanks was called for by farmers who paid 50 cents per two-horse wagon load. It was intimated that this charge might influence some of the farmers to belittle the value of the sludge to prevent any advance in price. The principal crops raised in this territory are garden truck, peaches, and some grain.

Farmer No. 14 had growing at the time of the survey potatoes and tomatoes, some of each fertilized with sludge and some with manure. He stated, as was obvious on inspection, that the sludged areas looked better than the manured, but the crop had not been harvested. In the experience of this man sludge was beneficial to celery. He considered sludge better than manure for heavy ground containing plenty of moisture, but the manure better for light dry land, sludge on this land burning up the crop.

No. 15 had used sludge for corn, peaches, and garden truck. He stated it was especially good for peach trees, and while on the whole he considered cow manure a better fertilizer, sludge being "too hot" in a dry season, he felt that sludge was a "good fertilizer."

No. 16 had used sludge for corn, tomatoes, and around orchard trees, applying 50 cubic yards per acre, the same as when using manure. He has had good results and considered sludge a "good substitute for manure."

No. 17 in 1919 fertilized three different patches of tomatoes, one each with sheep manure, tankage, and sludge. He was not able to notice much, if any, difference in the yield. In 1920 he was using sludge for early potatoes, parsley, celery, and onions, all of which looked good but had not ripened at the time of the survey. This farmer considered sludge as good as barnyard manure, richer, if anything, but cautioned against using too much.

Four or five more farmers were seen at Rochester. The consensus of opinion was that while, on the whole, sludge was inferior to manure it made a good substitute, being even better on heavy, wet land but likely to burn up the crop on light land or in a dry season. There was also more or less complaint of odors, especially on muggy days.

In Lexington, Ky., a few farmers had used sludge for tobacco and various other crops, but none felt that they had had sufficient experience with it to venture an opinion as to its value. Reports from this plant in 1921 indicate a rapidly increasing use and interest among the farmers.

These experiences are not given as proofs of the value of digested sewage sludge from sedimentation tanks. The personal equation, the lack of specific quantitative results, the absence of properly controlled comparisons with other fertilizers, and other factors, all prevent the statement of any definite conclusions. It is believed, however, that they have a distinct value and are worthy of serious consideration. The following is a general summation of the information obtained:

(1) Of 20 farmers interviewed at four cities, 6 considered sludge superior to barnyard manure, volume for volume (sludge used contained probably 60–75 per cent water); 5 considered it equal or nearly so; 5 considered it inferior, but 3 of the 5 held it to be a good substitute and in wet, heavy ground superior; and 4 ventured no opinion.

(2) With the decreasing production of manure, due to the rapid growth of the use of automobiles, sludge should be looked to more and more as a substitute for local use.

(3) Under certain conditions, the nature and extent of which have never been studied, sludge possesses a value greater than the chemical analyses of its plant food constituents would indicate.

(4) There is a difference of opinion as to the best method of applying sludge, whether as a top dressing or plowing under.

(5) There is more or less odor from sludge, especially when piled, and on muggy days, but this odor does not carry very far and is no more objectionable than many commercial fertilizers.

(6) The weed seeds in the sludge are not a serious objection to its use.

(7) Practical *large* scale experiments should be made with sludge to obtain quantitative data upon which to judge the value of sludge to the soil. In these experiments the "extra" plant food benefits of its use should be given due consideration. The farmers claim to be too busy to make tests, but they want to know among other things: (*a*) The best method of applying sludge—as a top dressing or plowing under; (*b*) the quantity to be used with different soils; (*c*) a direct quantitative comparison of the increase in yield obtained with sludge, barnyard manure, and some commercial fertilizers; (*d*) the lasting effect on the soil.

Hatfield[18] reports a series of fertilizer experiments using various types of dried sludge, dried blood, and some other commercial fertilizers. The experiments were practically all made with pot cultures, the results of which themselves indicated to the authors the necessity for field tests to determine, the proper amount of various sludges to be used to obtain the best results. In one series where activated sludge was applied in amount varying from one-half to 3 tons per acre, the best yield was obtained from 1½ tons, with, however, 3 tons giving practically the same results. In a second series one-half ton gave 30 per cent better results than any higher amount up to 20 tons per acre. This was explained by the fact that the pots containing the higher amounts over one-half ton per acre had been fertilized the year before and, on the basis of other tests, should show a decreased yield the second year. Imhoff tank sludge was used at 10 and 20 tons per acre rates, which is probably equivalent to 2 to 4 times that actually used by the farmers interviewed on the survey, most of whom cautioned against using excessive amounts The large amounts of Imhoff sludge were used to secure a nitrogen as high as other sludges and fertilizers used.

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[18] The Fertilizer Value of Activated Sludge, William Durrel Hatfield. Illinois State Water Survey Bulletin No. 16.

It is not to be expected that bed-dried sewage sludge can be placed on an equal footing with commercial fertilizers or return a profit on expensive methods of treatment, but it is believed that a demand for sludge can be developed among farmers in the vicinity of many treatment plants, that revenues can be obtained from it which will go a long ways toward paying for the unavoidable costs of handling at the plant, and that in the agricultural activities of a community there is an economic place for sludge produced by that community.

The production of a prepared fertilizer from sewage sludge appears to be economic only from sludge obtained from the activated sludge process. In Baltimore a contractor paid the city 82 cents per ton, 10 per cent moisture basis, for bed dried sludge delivered to his drying plant containing on an average 2 or more per cent nitrogen, which it did about two-thirds of the time. The contract calls for the delivery of sludge at 70 per cent water. At the time of the survey, July, 1920, the contract was near expiration and arrangements had not been made for the future. The superintendent of the plant felt that a well-designed plant averaging 17 tons of dried product per day could break even, and make money at 20 tons per day which is about equivalent to 70 tons of 70 per cent wet sludge. It would appear that this would depend upon the price obtainable for nitrogen, though the superintendent estimated that operating costs would follow nitrogen value. There was no difficulty in disposing of the product, the market for even the 2 per cent nitrogen material being greatly in excess, in 1920, of the output of the plant. Purchasers, it was stated, used the dried sludge as a base or filler for high-grade fertilizers.

In drawing any conclusions from this plant several factors must be considered: (1) The plant itself was in poor shape, probably improperly designed in the first place; (2) there was not sufficient sludge to allow uninterrupted operation; (3) the raw sludge had already been partially treated, the moisture having been reduced to about 70 per cent on the beds without expense to the contractor; (4) the market price of nitrogen was high; (5) the plant as it stands was, according to the superintendent, losing money.

Raymond Wells [19] places 3 per cent as the minimum ammonia content (about 2.4 nitrogen) below which any attempt at recovery is economically useless.

> From an economic and business standpoint, any goods falling below this rating had better be forgotten and no time wasted on developing methods of handling.

Others have placed 4 per cent nitrogen as a minimum figure for a salable product. Both of these values are higher than can normally be expected in average digested sludges. In spite of the recovery plant at Baltimore, it appears reasonable to conclude, as has already been stated, that the disposal of digested sludges from sedimentation tanks must be accomplished locally.

With the activated sludge process, however, it is reasonable to expect the sludge to contain at least 4 per cent nitrogen and probably more. Upon the economic value of the sludge depends the success or failure of the activated process for large installations. There may be exceptions, such as the necessity for concentrating the plant into a small area, or the demand for an unusually high-grade effluent, but, in general, the cost of the activated sludge process, involving the disposal of tremendous volumes of sludge, will be prohibitive unless the recovery of valuable sludge is able to partially pay for operating expenses.

The present developments of this method are sufficient to justify the statement that the recovery of sludge is feasible and the recovered product will pay for part of the operating expenses, but it is not possible to more than estimate the net cost of the process. Large experimental plants have given valuable data, but there is not in existence in this country any large plant operating under routine conditions at which the treatment and sale of sludge has been demonstrated.

The recovery process, which has already been described, consists of: (1) Concentration, with or without acidification, in sedimentation tanks; (2) partial dewatering by presses or centrifugal machines; (3) heat drying. None of these processes have as yet been standardized. Their feasibility has been demonstrated at testing stations, but they can not be said to have passed beyond the development stage.

Another factor to be considered is the market. The ability of the market to absorb the quantity of sludge which would be produced if many of the larger cities adopted the activated sludge process is yet to be determined. Some of the first plants may find a ready market for their product, but subsequent installations must consider the probable point of saturation.

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[19] Economic Values in Sewage Sludge, Raymond Wells. Municipal Journal and Public Works, Nov. 8, 1919.

Reports of the fertilizing value of dried activated sludge have been favorable. For the most part they have been "pot" experiments, but as such, they have been fairly conclusive. The experiments of Hatfield and Bartow [30] in 1915 and of Hatfield [31] in 1918 indicated that activated sludge gave better results than dried blood, gluten meal, or inorganic nitrogenous fertilizer, equivalent nitrogen being used in each case. The application and extension of such experiments to actual conditions on a large scale offers an attractive field of investigation.

The present status of the preparation of sludge for the commercial fertilizer market may be summed up as follows:

(1) The drying of sludge, digested or fresh, from the sedimentation processes for use as a commercial fertilizer can not be considered economically feasible because of the low nitrogen content.

(2) The drying of sludge from the activated sludge process, containing 4 per cent or more of nitrogen, for use as a commercial fertilizer offers attractive possibilities, but its success has not been demonstrated.

(3) The processes of drying are still in the development stage. They have been tried only at testing stations, some of which, it is true, have been of considerable size, but still test units.

(4) Improvements in the drying processes are to be hoped for and may be of sufficient value to firmly establish the principle of the utilization of sludge as commercial fertilizers.

(5) The value of sludge as a fertilizer has been demonstrated.

(6) The extent of the market for dried sludge is unknown.

Sludge digestion tanks.—The purpose of these tanks is to provide a place for the digestion of sludge outside of the sewage sedimentation tanks. Fresh sludge from plain sedimentation tanks, for example, is very foul and hard to handle on sludge beds, and is greatly improved by digestion in separate tanks. Such digestion tanks are also used for sludge from secondary sedimentation tanks, hydrolytic tanks, and, in some instances, septic tanks. As Imhoff tanks have within themselves provisions for this digestion of sludge, separate tanks for this purpose are seldom found with these tanks.

At Alliance the sludge from two plain sedimentation tanks is pumped to the Imhoff tanks which operate in parallel with them. These tanks, therefore, serve the double purpose of sewage sedimentation tanks and digestion tanks for plain sedimentation tanks.

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[30] The Value of Activated Sludge as a Fertilizer. Hatfield and Bartow, University of Illinois, Bulletin Water Survey Series No. 13.

[31] The Fertilizer Value of Activated Sludge. Hatfield, Illinois State Water Survey, Bulletin No. 16.

At Fitchburg one of the Imhoff tanks is used largely for the digestion of sludge from the secondary sedimentation tanks, being used to treat sewage only occasionally.

Baltimore was the only city visited where special tanks were installed for this one particular purpose, all sludge from the hydrolytic tanks being pumped to these tanks for digestion before disposal.

These three plants are the only ones surveyed in which sludge was digested in tanks other than those in which it was settled from the sewage, and Baltimore is the only one where such tanks have been designed and built for this purpose exclusively.

Sludge beds.—At 12 of the 15 plants surveyed, the sludge drawn from the tanks was applied to filter beds to dewater it to a condition whereby it could be handled economically.

These beds are generally constructed with bottoms sloping to open tile underdrains, about which is placed a layer of coarse gravel. The material over the gravel grades up to a surface of sand. It is necessary to provide a surface capable of retaining the solids while permitting free passage of water and arrangements below this surface to rapidly drain away the water thus filtered out. Layers of sand one-fourth to one-half inch deep have proven sufficient, but as some sand, probably about one-fourth inch, is lost at each cleaning of the bed it is more economical to provide sufficient sand for several cleanings rather than replace it after each cleaning.

Total depth beyond that necessary to grade the material from sand to 1 or 2 inch stone or gravel around the drains does not appear to be of any particular benefit, as no effort is made to oxidize the effluent in the bed. A 12 to 15 inch total depth with a 2 to 4 inch surface of sand should be adequate.

The idea of covering the beds with a glass structure, such as a greenhouse, to protect drying sludge from rain and to permit of all year operation, was originated at the Cleveland sewage testing station in 1913. Results there indicated that, for local conditions 1 square foot of glass-covered beds was equivalent to 2 square feet of open beds. On the basis of these results, the covered beds at Alliance and Canton, Ohio, were installed. At both the plants the plant operators are advocates of the glass-covered beds, claiming that they are less dependent upon weather conditions and worth the extra money invested.

At Canton records of sludge removed from beds during the period January, 1917, to June, 1918, are available. During this period 39 glass-covered beds and 28 open beds received sludge. During the months of December to April, inclusive, the covered beds received 22 doses against 15 for the open beds, and the sludge was on the beds an average of 32 instead of 43 days. Attention is called to the fact that the time on the beds does not necessarily mean necessary drying period, as sludge may be left on the beds longer than necessary due to lack of labor to clean the beds, etc. During the months May to November, inclusive, the covered beds received 17 applications and the open beds 16, or practically the same. The time on the beds for this period averaged 27 for the covered beds and 35 for the open. The total for the entire period of 17 months was 39 doses for the covered beds and 28 for the open beds. The area of both types of beds is the same, but with a bed of each type available the preference was given to the covered beds. Unfortunately, therefore, the data admit of only a relative comparison of the two types of beds.

In the following table the sludge beds at the plants surveyed are arranged for comparison:

TABLE No. 64.—*Sludge beds at plants studied.*

	Alliance.		Atlanta.		Baltimore.	
	Glass covered.	Open (reserve).	Intrench. Creek.	Peachtree Creek.	Design basis.	Operating basis.
Total depth (inches)	33	33	13±	13±	12-30	12-15
Depth sand layer (inches)	11±	None.	½	½	3-18	4
Underdrainage provided	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Bottom [1]	N.	N.	N.	N.	N.	N.
Tracks on beds	Yes.	No.	Yes.	Yes.	Yes.	Yes.
Total prepared area (acres)	0.235	0.766	0.41	0.41	1.02	5.05
Average depth of dose (inches)	6-10	No record.	8	8	12	7
Average drying period (days)	8-14	No record.	[2] 12	[2] 12	10-21	3-21
Average m. g. d. sewage treatment	2.6		5.0	12.0	14.0	55.0
Population served (thousands)	20.0		30.0	75.0	112.0	530.0
Area per m. g. d. (thousand square feet)	3.91	12.8	3.58	1.49	5.7	4.0
Area per capita (square feet)	.51	1.66	.60	.24	.71	.42
Area per p. p. m. suspended matter per m. g. d. (square feet)	25.7	82.9	33.7	6.5	....	25.1
Area per p. p. m., suspended matter removed, per m. g. d. (square feet)	47.2	152.0	91.6	9.4	....	77.0
Is area adequate	Nearly.	Seldom used.	Yes.	No.	....	....

	Canton.		Columbus.	Fitchburg.	Lexington.	Rochester.	
	Glass covered.	Open.				Brighton.	Irondequoit.
Total depth (inches)	16	16	8-12	8	12	12	19
Depth sand layer (inches)	15	15	1	8	½	2	5
Underdrainage provided	Yes.	Yes.	Yes.	No.	Yes.	Yes.	Yes.
Bottom [1]	N.	N.	N.	N.	N.	Puddled clay.	N.
Tracks on beds	Yes.	Yes.	Yes.	Yes.	Yes.	No.	[3] No.
Total prepared area (acres)	0.25	0.25	2—	0.42	0.40	0.08	1.78
Average depth of dose (inches)	8	8	8	10	18	9-10	8-9
Average drying period (days)	10-30	10-30	14	29	[2] 9	7	10
Average m. g. d. sewage treatment	4.4		16.8	3.35	2.5	1.0	32.5
Population served (thousands)	60.0		225.0	37.0	28.0	8.0	240.0
Area per m. g. d. (thousand square feet)	4.95	....	5.18	5.46	6.97	3.48	2.38
Area per capita (square feet)	.36	....	.39	.49	.62	.42	.33
Area per p. p. m., suspended matter per m. g. d. (square feet)	19.0	....	26.1	18.4	37.4	33.3	12.7
Area per p. p. m., suspended matter removed per m. g. d. (square feet)	29.4	....	30.8	23.3	70.4	55.1	34.5
Is area adequate	No.	....	No.	No.	Yes.	Yes.	Yes.

[1] N=natural ground.

[2] Except during winter season.

[3] Traveling crane places car bodies on bed where desired.

At all the plants listed the sludge is digested either in Imhoff tanks, or in special tanks. In the Emscher district, Germany, where the Imhoff tank originated, it was customary to provide 1 square foot of sludge-bed area per three to four persons. This figure was adopted in this country with the Imhoff tank, and used for design. In the above table the sludge-bed areas at 10 plants are given. Of these only 1 provides for less than 0.32 square foot per capita, 5 for 0.32 to 0.51, and 4 for more than 0.51. If the reserve area at Alliance is not considered, only 3 plants provide more than 0.51 square foot of bed per capita.

The Intrenchment Creek plant at Atlanta and the Irondequoit plant at Rochester are the only ones with a factor of 0.33 square foot per capita, and at both these plants the area is considered adequate. At Fitchburg the beds were designed with this factor, but are operating at about 0.5 square foot per capita. Even this has not proven adequate. Sludge is lagooned in low areas, the plant operator estimating that the sludge bed would have to be doubled in area to take care of all sludge. This would mean 1 square foot per capita.

At Columbus, with 0.39 square foot per capita available, the operator stated that three to four times as much was needed. The estimated needed areas at other plants brought the required areas up to an average of 0.6 to 0.85 square foot per capita, with some considerably higher.

On the whole it would appear that 0.33 square foot per capita was, on the average, inadequate and that it should be two to three times that amount.

Downes, [37] reporting on the operation of a plant at Plainfield, N. J., computes from his data a sludge-bed requirement of 0.686 square foot per capita. In discussing the drying period he states:

> It is surprising to find that, in spite of the fact that a coat of sludge 9 inches thick will become spadable in a week or 10 days of good drying weather, under actual climatic conditions, we have averaged only a scant 6 dryings per year. The figures for three years are 5.8, 6, and 5.8 dryings per bed a year.

This illustrates the danger of computing sludge-bed area using an assumed number of cleanings based on average drying periods.

Adequate sludge-bed area means much in the operation of a plant. The only way to effectively overcome foaming in Imhoff tanks is the withdrawal of sludges, and beds should be available when needed for this purpose. With just sufficient bed area, a rainy season or temporary shortage of labor may necessitate carrying overloaded sludge compartments in tanks over the winter.

No part of a treatment plant is less expensive than the sludge beds. Where area is available, the cost of a liberal bed installation is but little more than the minimum requirements. From the table it would appear that under American conditions the majority of the plants require a minimum of 0.5 square foot per capita, and that 0.8 or even 1 square foot per capita is a safer design figure, especially where facilities for lagooning or wasting in low lands are not available, and entire reliance must be placed on the beds.

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[37] Operating Data of Fine Screens and Imhoff Tanks. John R. Downes. Public Works, vol. 50, pp. 370-371.

Sludge is formed from the suspended solids removed from the sewage in its passage through the tank. These removals at different plants have been equated in Table No. 64 with the sludge-bed areas, to obtain the number of square feet available per part per million of suspended matter removed per million gallons daily. These computations are based on the results of analyses made on the survey, which, with possibly one or two exceptions, are believed to be fairly representative of the various plants. The figure for Alliance is very high only if the reserve bed, which is seldom used, is taken into consideration. The result for the Intrenchment Creek plant at Atlanta may be slightly discounted due to abnormal conditions at the time of the survey, and the same may be said to be partially true of the extremely low figure for the Peachtree plant at Atlanta. In this case, however, no proper allowance would bring the figure to within the range of most of the plants which is between 23.3 and 77. Of the plants at which opinions regarding the adequacy of the sludge were expressed only one, the Irondequoit plant at Rochester, having less than 45 to 50 square feet available per parts per million of suspended matter removed per m. g. d. had sufficient area. Based on these very few results a minimum of about 50 appears to be a safe factor.

The average suspended-matter content of the raw sewage at 12 plants surveyed where sedimentation tanks were used was 177, and the value corresponding for the tank effluents was 75. There was an average removal, therefore, of 102 parts per million. Allowing 50 square feet of sludge-bed area per parts per million per m. g. d., the average minimum requirement of the plants studied is about 5,000 square feet per m. g. d. The average per capita contribution to the sewers for these 12 plants is within 1 or 2 gallons of 100 gallons per day. Using this per capita flow the average minimum sludge-bed requirement becomes 0.5 square foot per capita.

APPENDIX I.

DETAILED DESCRIPTION OF TREATMENT PLANTS STUDIED.

I. ALLIANCE, OHIO.

As described in the body of this report, the sewers contributory to the Alliance treatment plant are divided into the high-level and the low-level systems. The high-level system flows by gravity to the plant, but the low-level, while reaching the plant by gravity, must be pumped to the treatment devices. Before reaching the pumps, however, it is passed through an old treatment plant. As the treatment thus received is probably of little if any value in the operation of the treatment plant proper, it is described elsewhere as part of the sewerage system and this section deals only with the main treatment plant, including, however, the pumping plant for the low-level system.

Pumping plant.—All sewage from the low-level system is received at the treatment plant in a storage basin or pump well. This well is 9 feet 6 inches deep, sloping to 10 feet 3 inches in a length of 24 feet. The width is 13 feet 10 inches. These are inside dimensions. The bottom of the well is 15 feet below ground.

The sewage enters this well through a 1½-inch clear opening bar screen in a small screen chamber from which it passes to the storage well in a 24-inch vitrified pipe. When there is 3 feet of sewage in the well a float trips a Yoemans Bros. (Chicago) control switch and starts one of two vertical Watson induction motors shaft connected to an 8-inch centrifugal pump. Pumping continues against a head of 21 to 24 feet, depending on the depth of the sewage in the well, till the well is emptied, when the float cuts off the current to the motors. The pumping equipment is housed in a brick building.

The volume of sewage pumped is not measured separately, but with the sewage in the high-level or gravity system. In 1916 the designer, Mr. R. W. Pratt, estimated the low-level sewage to be 25 per cent of the total or 0.5 m. g. d. The pumps are stated to operate 20 minutes out of each 50. If the pumps deliver 700 gallons per minute (specification required not less than 700) the volume would be about 0.403 m. g. d. Probably 0.5 m. g. d. is approximately correct.

Entrance flumes.—As originally designed, the plant had three parallel grit chambers preceding the screen. It was found, however, that considerable sludge was deposited, due to checked velocity when the screen was clogging. The grit chambers are, therefore, now used merely as entrance flumes to the plant. The central chamber has been abandoned altogether, one of the others has had a false bottom installed and receives the high-level sewage from a 30-inch sewer, and the third one receives the sewage from the low-level sewers pumped by the plant described above. Both chambers discharge into a common flume to the screen and tanks.

Screen.—This is located in the flume. The screen chamber is rectangular in shape and contains a bar screen with three-fourths inch clear openings set at an angle of 60 degrees with the horizontal. The screenings are raked to a platform at the top of the screen and wheeled away to a dump.

Plain sedimentation tanks.—There are two tanks operated as plain sedimentation tanks. These tanks are (inside dimensions) 132 feet long by 42½ feet wide by a depth sloping from 9 feet at the inlet to 10 feet at the outlet. In addition to the longitudinal slope, the bottoms slope about 9 inches from the sides to the center.

The inlet and outlet channels, 4 feet wide, are contained within the tanks themselves, the entrance to the tank being through openings along the back side of the

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channel controlled by iron slide or stop gates. Sewage is thus compelled to pass behind and under the channel. A central pier supporting the channel is supposed to diffuse the flow across the cross section of the tank. The outlet has a similar arrangement except that the flow is over adjustable weirs instead of under stop gates. The outlet channel leads to a well from which the effluent is taken to the control houses of the contact beds.

At the outlet end of the tank, in the corner adjacent to the other tank, is located a draining chamber 5½ feet wide by 12 feet long. Three 12-inch sluice gates from each tank open at different elevations into this chamber, permitting the drawing off of supernatant to an old filter bed when cleaning a tank, but without carrying out the scum. The scum can be drawn off the top into the clean sedimentation tank or it can be collected with the sludge.

Each tank has a single 12-inch sludge outlet, toward which the sludge is pushed or washed. The sludge is taken to a 200-gallon ejector set in a pit 7 feet 8 inches wide by 12 feet long by 13 feet 10 inches deep, located in an adjacent contact bed. This ejector discharges into the Imhoff tanks where the sludge is held for digestion.

There are inlet and outlet baffles, the outlet one acting as a scum board.

The total capacity of each tank is 400,000 gallons. The available sewage capacity is somewhat less, probably about one-third million gallons.

Imhoff tanks.—These tanks were constructed inside a third tank of the same size as those already described, the bottom being cut out to obtain necessary depth. As built, the Imhoff tanks are laid at right angles to the old tank inside of which they were built.

There are two unit sets of tanks, each unit consisting of four tanks, or it might be said, a four-flow channel tank, as the four sludge compartments are all connected by openings, 4 by 6 feet, in the walls between them, and through the slots.

The length of each flow channel from the inlet to the outlet weir is 35 feet 2 inches. Each is 12 feet 3 inches wide, and, from the top of the tanks to the slot, about 13 feet 5 inches deep. The flow line is 1 foot, plus or minus, below the top of the tank, depending on the elevation of the adjustable weirs. Three gas vents, each 2½ feet clear width and 24 feet 7 inches clear length, separate the four flow chambers.

The sides of the tank and gas vents are vertical to a depth of 7 feet 3 inches where the bottom slopes start. These bottoms are on a slope of 6 feet 10 inches vertical to 6 feet 1½ inches horizontal. These slopes are in all four directions so that the slots run lengthwise and across the tank. The slots have a clear opening of about 7 inches and an overlap of about 9 inches.

The inlet and outlet for each channel consist of two 1-foot adjustable weirs. There are inlet and outlet baffles or scum boards consisting of four 2 by 10 boards extending 30 inches below the sewage and located 6 feet from the weirs.

The influent and effluent channels, each 3 feet wide by 3 feet deep, are contained within the walls of the original plain single story tank. The valves and gates on these channels are arranged to permit the reversing the direction of the flow in the tank.

Each unit or set of four flow channels has three digestion chambers with three hoppers, one under each gas vent. These are 22 feet 11 inches long, 15 feet 8 inches wide and 13 feet deep from the slot overlap to the bottom of the hoppers. The hoppers which underlie the entire digestion chambers are 5 feet deep. The flat bottoms are 2 by 2 feet, giving a slope of 1 to 1.4 to the sloping hopper bottoms.

Around the top of the hoppers is a 1½-inch galvanized-iron water pipe with three-sixteenths-inch holes drilled on 18-inch centers. From this a three-fourths-inch line runs to the bottom of the hopper and turns up at the mouth of the sludge pipe.

The 8-inch sludge pipes, one for each hopper, rise vertically to the top of the tank. At a point 4 feet below the flow line a horizontal pipe takes off and out through the sides of the tank to a sludge gutter, 2 feet wide by 3 feet 10 inches deep.

All sludge or digestion chambers in each unit are connected by openings 4 by 6 feet. This opening is cut right at the top of the hopper.

The sludge from the plain sedimentation tanks, as already mentioned, is pumped to the sludge chambers of the Imhoff tanks for digestion. An 8-inch pipe from the ejector is carried to and turned down into the gas vents of the Imhoff tanks. This arrangement is open to the question as to whether the discharging of large volumes of sludge under high velocity and pressure does not create a positive pressure in the digestion chamber, stirring up sludge and forcing it up through the slots into the flow channels. It is a fact that all flow chambers were continually covered with a heavy scum, which could not be satisfactorily accounted for by deposition of sludge along the bottom slopes of the flow chamber, though this was undoubtedly partially responsible.

The capacity of each flow chamber is 4,120 cubic feet. As designed the detention period should be two and one-half to three hours with a lineal velocity of 0.243 foot per minute. The digestion chamber of each unit of 3 hoppers is 10,490 cubic feet or about 2,620 cubic feet for each flow chamber. This was considered, when designed, adequate for five to six months' storage.

The available sludge data at the plant confirms the five-month estimate. In the year May, 1919, to April, 1920, 940 cubic yards of sludge of about 80 per cent moisture were removed from the sludge beds. This is approximately 80 cubic yards a month of 80 per cent sludge or 160 cubic yards with an assumed moisture in the tanks of 90 per cent. The accumulation per flow channel is therefore about 20 cubic yards per month or 100 cubic yards per five months, and the sludge storage capacity per flow channel is 97 cubic yards.

The effluent from the Imhoff tanks joins that from the settling tanks either in the diversion chamber of the contact beds or in the channel to it.

Contact beds.—There are 12 contact beds arranged in 3 units of 4 beds each. Each bed has an area of one-fourth acre which gives an acre to each unit. These beds were originally built in 1910, but some were more or less modified in 1917.

The following table covers some of the main features of the various beds, as they stand at present.

TABLE NO. 65.—*Structural features of contact beds at Alliance, Ohio.*

	Bed numbers.
Full concrete bottoms	1, 2, 5, 6, 8, 10, 12
Partial concrete bottoms	3, 4, 7, 9, 11
Filtering material washed in 1917	4, 5, 7, 9
Media, 18-inch slag, ¾-1½ inch, 36 inches; cinders, ⅛-¼ inch	4, 5, 7, 9
Media, 48 inches; cinders ⅛-¾ inch	1, 2, 3, 6, 8, 10, 11, 12

In 1910 complete concrete bottoms were placed where such were deemed necessary, while in the others the bottoms were only partially concreted. The beds with complete bottoms were Nos. 1, 2, 6, 8, 10, and 12. In 1917, when the filtering material was taken out from beds Nos. 4, 5, 7, and 9 and washed, a concrete bottom was placed in No. 5.

In replacing the washed material slag 18 inches deep was placed over the underdrainage system, which also was slightly altered. The filtering material in the other eight beds, Nos. 1, 2, 3, 6, 8, 10, 11, and 12, was left as placed in 1910.

The underdrainage system consists of 3-inch tile drains laid 11 feet apart over the entire bottoms, which slope on a 4 per cent grade to two collecting lines, varying in diameter from 8 to 12 inches. These in turn empty into a collecting well at the common apex of each four units, from which it can be discharged onto the secondary sand filters or directly into the Mahoning River.

The distributing system consists of a wooden trough 4 feet wide by 2 feet deep, running from the control house diagonally across the filter for a distance of 36 feet.

Within the trough is placed a 12-inch layer of one-half to 1-inch gravel. Sewage leaves the trough through small screens 7 by 6⅝ inches, with one-fourth-inch clear openings, set at 2-foot 6-inch centers at the bottom of each side of the trough, and hence below the gravel in the trough. The pipe extension of the trough is surrounded by 4 feet of the same gravel as in the trough.

The operating control of the beds start at the chamber receiving the effluent from the tanks. Here hand-operated valves control the lines to the three head houses. In these houses are located alternating siphons, which rotate the dosing of four beds which corner at the head houses. Any one bed can be thrown out of operation, and an automatic release makes overlapping of beds impossible. The installation was provided by the Pacific Flush Tank Co. The houses themselves are low, brick structures.

The contact beds are not operated the year around. They are started about the middle of May and discontinued late in November. During the winter tank treatment is all the sewage receives. The filling period depends on the rate of flow of the sewage. It is estimated that 2½ to 3 hours is consumed in filling, about 20 minutes retention, and 2½ to 3 hours emptying, followed by 4½ to 6 hours' rest.

Intermittent filters.—In the original installation three 1-acre units of fine cinder filters were constructed, later two more have been added, but at present one unit is used for sludge drying, one for treatment of sedimentation tank effluent when the tanks are drained for cleaning, and three for secondary treatment following the contact beds.

These filters are operated only during the hot summer months, as a rule from the middle of June to the end of October. The effluent from the contact beds is collected into a common line, from which it can be discharged through sluice gates onto any one of the three fine filters.

The filtering medium in two of the three filters consists of coarse cinders around the underdrains, then about 30 inches of fine cinders with a surface layer of 2 to 4 inches of sand. The third filter, constructed in 1917, has a slag covering over the underdrains, then a little less than 2 feet of screened cinders and finally 6 inches of sand. The depth of the coarse cinder or slag layer varies over the filter, at the extreme sides the slope of the lateral drains reduces it to less than 1 foot.

In principle the method of applying the sewage is the same for all filters, wood troughs running across the surface with diagonals reaching to within 10 to 20 feet of the sides. On the two old filters the lateral troughs are spaced 75 feet apart, but in the new filter this is 90 feet.

The collecting or underdrainage system is similar in all, but more complete in the new than in the old filters. In the old ones, the lateral drains, at right angles to a central collector, are spaced about on 38 to 40 foot centers while in the new filter they are placed on about 9-foot centers. The lateral drains discharge into a central collector which in turn discharges into the Mahoning River, each filter having an independent outlet. Each filter has 5 to 8 ventilators on the margin of the beds, consisting of 8-inch tile extending down and connected with the underdrains.

At the time of inspection these filters had not been put in operation for the season. It was stated that the regular schedule called for the continuous operation of a filter for two days, during which time it received the entire effluent from all the contact beds. This schedule gives a four-day rest after each two days of operation.

Sludge disposal.—As already described, the sludge from the sedimentation tanks is pumped to the Imhoff tanks for digestion. The sludge channel into which the sludge pipes from the Imhoff tanks discharge (see under Imhoff tanks), outlets to a 100-gallon Pacific Flush Tank Co. ejector. This ejector pumps the sludge to the sludge beds. The ejector is housed in a small brick building over a concrete pit, located in one of the contact beds adjacent to the Imhoff tanks. Besides the ejector this building houses the compressor, motor, and air-storage tank for this ejector and also for the ejector pumping the sludge from the plain to the Imhoff tanks.

One of the original fine cinder filters is used for sludge drying. The sludge is received at the drying area through a 6-inch force line from the ejector.

The drying area consists principally of 8 specially prepared beds which have been covered by a glass building of greenhouse construction. The remainder of the 1-acre filter unit is accessible and available, and is used from time to time for excess sludge. No changes, however, were made in the uncovered section to particularly adapt it to sludge drying. In general it has 33 inches of fine cinders over an underdrainage system as described for the intermittent filters. Sludge is applied at one point and allowed to flood over the entire bed.

The 8 special beds are each 20 feet wide by 64 feet long. These beds are arranged in two sets of four each divided by a concrete wall which carries the 6-inch sludge line from the ejector. Valves on crosses in this line furnish the control over each individual bed. Each opening is turned down over a concrete splash plate 3 by 3 feet, which is the only point of application. The four beds of each unit are separated by 9-inch concrete walls. Narrow gauge, 24-inch tracks run down the center of each bed. These are laid with the ties flush with the bed so that there is minimum lift from the beds into the cars. All tracks connect to a feed or ladder track to two sludge dumps.

The filtering material consists of the original fine cinder bed material for a depth of 1 foot 8 inches to 2 feet over the drains and a surface of 9 to 13 inches of sand. Over each underdrain is a section of gravel 18 inches wide and about 2 feet deep.

The underdrainage consists of a main 8-inch line, increasing to 10 inches, located near the dividing wall between the two 4-bed units. From this 4 or 8 inch laterals run the length of the beds and are plugged at the ends. Beds Nos. 1 and 3 have one 8-inch main lateral with 3-inch sublaterals across the beds, while beds Nos. 2 and 4 have two 4-inch longitudinal drains with no sublaterals.

Overflows and by-passes.—The first overflow is a weir at the end of the old grit chambers, or, as now used, influent channel. The outlet below the weir is a 24-inch pipe direct to the Mahoning River. As the weir, consisting of two 2 by 6 inch planks, can be drawn, this pipe can be used as a by-pass. The effluent from the tanks can be by-passed around the filters, and this is done during the winter. Finally the effluent from the contact beds can be, and, during certain seasons, is by-passed around the secondary fine cinder filters. To protect contact beds there is an overflow weir in each control house.

II. ATLANTA, GA.

A. INTRENCHMENT CREEK PLANT.

Sewage is received at the Intrenchment Creek plant, Atlanta, Ga., in a 4-foot diameter concrete sewer. This empties into a channel 4 feet wide by 4½ feet deep.

Screen.—This is located in the entrance channel. It is 4 feet wide, the width of the channel, and 8 feet long, set at an angle of about 34° to the horizontal. The bars are three-eighths inch, set with a clear opening of 1½ inches. Cleaning is by hand, the screenings being raked to a concrete platform at the top of the screen.

Grit chambers.—This installation follows the screen and consists of 3 parallel chambers each 30 feet long by 4 feet wide. As originally built the bottom sloped up from a depth of 8 feet 6 inches at the inlet to 4 feet 6 inches at the outlet, with a groove down the center of each chamber in which was laid a 6-inch drain to a manhole with an outlet to the creek. This arrangement was later modified by filling the grit chambers with large stone to make a level bottom 4 feet 6 inches deep, and by removing the upper third of the tile drain. Grit is now removed by flushing it to the outlet into the 6-inch drain to the manhole, and thence through an 18-inch line to the creek.

A fourth channel, parallel with the grit chambers, was originally constructed as a by-pass, but it has been filled and, for operating purposes, does not exist.

Measuring device.—The flow of sewage is measured by a Stevens recording float gauge, which records the head over the inlet weirs to the tanks. At the time of inspection this gauge was out of commission and was said to have been so for the past three years.

Channels to tanks.—Leaving the grit chamber, the sewage enters a 42-inch pipe to the inlet chambers of the tanks. After passing the first chamber, which serves a little over half of the tanks, the 42-inch pipe is reduced to 36 inches.

From the inlet chamber the sewage can be turned into a channel 3 feet wide by 3 feet 9 inches deep from which it flows over weirs into the tanks, or it can be passed under this channel through a 30-inch crossover conduit to an inlet chamber at the other end of the tanks, and thence to a distributing channel for the weirs on that end of the tanks. By this arrangement the direction of flow in the tanks can be reversed. The same channels are used for outlets as well as inlets.

Imhoff tanks.—These consist of 21 tanks arranged in 7 groups of 3 tanks each. The 3 tanks in each group operate in series, but in reality they are more like one tank, as will be explained later.

Each tank is a combination of the rectangular and circular types of construction. The digestion chamber is circular and the walls of this section extend up to the top of the tank. At each end, however, the walls are cut to allow the full width of the settling chamber to extend from one tank to the next in the series.

The over-all maximum inside dimensions of each tank are: Length 31 feet 10 inches, width 25 feet, depth 26 feet.

As stated above, the settling or upper story section of the tank extends beyond the sludge wells. The total length of this section is 31 feet 10 inches and its width 20 feet. The sides are vertical for a depth of 7 feet 3 inches where the bottoms start to slope on a 1 to 1½ slope for a depth of 6 feet 11 inches to a 10-inch horizontal opening slot with a 7-inch overlap. The other slopes forming the slots with the sides are formed by an inverted V partition, with the apex at the center of the tank at the same elevation as the top of the side slopes. Those portions of the settling sections which extend beyond the digestion chamber are connected thereto by an apron sloping from the end of the tank to the end of the slot over the digestion chamber.

There are three gas vents, a central chimney rising from and venting the inverted V section, and two side vents. The central vent is 14 feet 8 inches long by 1 foot 6 inches wide. The side gas vents are segments of a circle of 25-foot diameter subtended by a chord 14 feet long. The maximum width is 2 feet 2 inches.

About 16 inches from the inlet and outlet weirs of each unit of 3 tanks are located scum boards extending down 24 inches below the flow line. There are two other "down" baffles, one on each side of the gas vent at the center of the tank, extending down 6 feet below the flow line or the ridge of the bottom partitions. Between the three tanks of a unit there are "up" baffles extending to within 30 inches of the flow line, which is 15 inches below the top of the tanks. The capacity of the flow chamber from the flow line to the slots is 41,000 gallons.

The digestion chamber is circular, 25 feet in diameter and 10 feet 3 inches deep below the overlap of the slots. The sides are vertical for 5 feet, at which point the hopper bottom begins. This is 6 feet 3 inches deep, cone shaped, with slopes of 2 to 1.

The sludge outlet is an 8-inch iron pipe rising vertically from a point just off the center of the hoppers. This pipe extends to the top of the tank through the central gas vent and is capped. Six and one-half feet below the top, a horizontal lateral is taken off across the tank, runs through the side and discharges into a sludge pit, from which the sludge is carried to the drying beds or other disposal points.

A 1-inch lead water pipe is run down to the center of the hopper below the sludge outlet. From this pipe a 1-inch branch extends around the hopper 15 inches from the top, and both lines have one-eighth-inch holes drilled on 18-inch centers. Mr. C. C. Hommon, supervising chemist, stated these pipes were never used and he considered them unnecessary. The capacity below the overlap of the slot is 3,000 cubic feet.

Dosing tank.—From the tanks the sewage passes through a 42-inch conduit to the trickling filter dosing tank.

This tank, for which plans were not available, was said to be of the same design as that for the dosing tank at the Peachtree plant, which is described in detail later in connection with that plant. There are three Merritt siphons, two dosing one-half acre each, and one a full acre.

Trickling filters.—There are two units of trickling filters of 1-acre area each. Sewage is received in a 30-inch main distributor from the siphon or dosing tank. This distributor is carried down the center of each filter in a gallery 6 feet wide with an average clear height of 10 feet. From the 30-inch distributor 6-inch laterals are taken off on 11-foot 8-inch centers. These are supported on 3-inch wrought-iron posts spaced on 13½-foot centers, the top of the laterals being 9 inches below the surface of the stone comprising the filter. Every 13½ feet, 6 by 6 by 3 inch tee's are set in these lines and the nozzles, Merritt type, set in the 3-inch openings. By staggering nozzles on adjacent laterals a uniform spacing of 13½ feet over the filter is obtained.

The filtering material consists of Georgia granite 1½ to 2½ inches in size, and the depth varies from 5½ to 6 feet, the difference being caused by the slope of the bottom.

The underdrainage consists of 6-inch half tile laid on 9¾-inch centers on a concrete bottom sloping 6 inches in 13½ feet to a 15-inch channel drain molded in the bottom. Over the half tile, small concrete slabs 18 by 24 by 3 inches are laid with 1-inch openings, to support the filtering material.

The 15-inch lateral drains, laid parallel with the main filter gallery, are spaced on 27-foot centers. They have a slope of one-half foot in the length of the filter, and discharge into a main effluent pipe 24 to 36 inches in diameter located at the lower end of the filter. This pipe drains toward the center and discharges into a 42-inch outfall pipe to Intrenchment Creek.

Over the 15-inch laterals and spaced on 23-foot 4-inch centers, are located 8-inch cast-iron ventilators, extending 3 feet 2 inches above the surface of the stone and capped with a cowl. There are no means provided for flushing the distributing or collecting systems.

Sludge beds.—The prepared sludge drying area is 172 feet long by 112 feet 6 inches wide. This is divided by brick partitions into four main beds, each 26 feet wide. The four beds are again subdivided into four smaller ones by transverse brick partitions. The smaller unit is, therefore, 43 feet long by 26 feet wide. The beds as a whole are surrounded by an earthen embankment.

Through the center of each main bed, there is a concrete channel 18 inches wide by 12 inches deep with a semicircular trough, of 10-inch diameter, molded in the bottom with its invert 1 foot above the surface of the sand in the bed. Sluice gates every 43 feet discharge on both sides of the channel onto 3 by 3 foot concrete splash plates set 2 to 3 inches above the surface of the bed. The concrete channels are connected outside the bed by 8-inch pipes to 2-foot square manholes with sluice gates. An 8-inch vitrified pipe from the Imhoff tanks carries the sludge to the manholes.

Over the channels are narrow, 24-inch gauge tracks connected to a ladder track at the lower end of the bed by turntables.

The filtering material consists of one-quarter-inch mortar sand, 2 inches of one-sixteenth to one-quarter-inch gravel, 5 inches of one-quarter to 1-inch gravel, and 3½ to 9½ inches of 1 to 2½-inch gravel.

The drainage system consists of two 8-inch main drains running the length of the bed, into which 4-inch lateral drains are connected on 7-foot centers. The bottom, natural ground, slopes both ways from the 4-inch drains to ridges between them. The 8-inch line is laid on an 0.8 per cent and the 4-inch laterals on a 1 per cent grade.

In addition to the prepared beds some sludge has been run onto adjacent fields and low lying areas.

Sewage pumps.—The location of the plant is such that city water is not available. The effluent from the tanks is used for washing and sprinkling purposes, being pumped by a 2-inch horizontal centrifugal pump direct connected to a 10-horsepower Wagner motor.

By-passes.—By-passes are so arranged that it is possible to cut out either the tanks or filters, or both, or to pass sewage around the entire plant, which it is customary to do at times of storms.

Miscellaneous.—As originally built, roughing filters were provided between the tanks and trickling filters. These, however, have never been used and for operating purposes are practically nonexistent.

B. PEACHTREE CREEK PLANT.

Sewage is received at the Peachtree Creek plant, Atlanta, Ga., in a 4-foot diameter concrete sewer. This empties into a channel 5 feet wide by 5½ feet deep.

Screen.—This is located in the entrance channel. It is 5 feet wide and 10 feet long, set at an angle of about 34° to the horizontal. The bars are three-eighth inch, set with a clear opening of 1½ inches. Cleaning is by hand, the screenings being raked to a concrete platform at the top of the screen.

Grit chambers.—This installation, following the screens, consists of three parallel chambers each 30 feet long by 5 feet wide. As originally built the bottom sloped up from a depth of 9 feet 8 inches at the inlet to 5 feet 6 inches at the outlet, with a groove down the center of each chamber in which was laid a 6-inch tile drain to a manhole with an outlet to the trickling filter drains. This arrangement has been modified by covering two-thirds of the drain from the inlet with slag, removing one-third at the outlet, and leveling the bottom with large stone and sand to give a uniform depth of 5 feet 6 inches. A 12-inch pipe was laid from the manhole, receiving drainage from the 6-inch tile to the creek. With these modifications it is now customary to clean the grit chambers by flushing the deposits direct to the creek.

A fourth channel parallel with the grit chambers was originally constructed as a by-pass, but this has been filled and, for operating purposes, does not exist.

Measuring device.—The flow is measured by a Bristol recording gauge, actuated by a McDougal Dexter compressed-air device, reading the head over the weirs of the Imhoff tanks.

Channels to tanks.—Leaving the grit chambers, the sewage enters a conduit to the tanks. This is a 48-inch line to the inlet chamber of the first battery of 12 tanks, and continues thence, reduced to 42 inches, to the inlet chambers of the second battery of 12 tanks and the third battery of 6 tanks.

From the inlet chambers the sewage can be turned into a channel, 3 feet wide by 3 feet 9 inches deep, from which the weirs to the tanks are fed, or it can be by-passed under this channel through a 30-inch crossover conduit to another chamber at the other end of the tanks and thence to a distributing channel for the weirs on that end of the tanks. By this arrangement the direction of flow in the tanks can be reversed. The same channels are used as outlets as well as inlets.

Imhoff tanks.—This installation consists of 30 tanks arranged in 10 groups of 3 tanks each. The 3 tanks in each group operate in series, in reality as one tank except that there is a distinct demarcation between the tanks.

The individual tanks are of the same design as those at the Intrenchment Creek plant. Reference is, therefore, made to the description at that plant, noting, however, the following differences in dimensions. The total tank length—that is, the length of the chambers—is 32 feet 2 inches instead of 31 feet 10 inches, and the central gas vents are 6 feet instead of 14 feet 8 inches long, the width being the same.

Dosing tank.—A 42-inch conduit, increasing to 48 inches, takes the tank effluent to the dosing tank of the trickling filters. The sewage enters the receiving channel of this tank through two 36-inch pipes. The dosing tank, which is divided into three sections, has a total inside length of 55 feet, width of 21 feet, and depth of 9 feet 2 inches. The receiving channel extends the entire length and is 3 feet wide by 5 feet deep, the bottom being 4 feet below the high-water level in the discharge chambers.

The sewage flows from the inlet channel over three 5-foot weirs into three separate though connected siphon chambers. Any of the weirs, however, may be blocked by stop planks, the pipe connection between the chambers closed, and the section of the filter controlled by that siphon put out of operation.

The central siphon chamber is 20 feet by 17 feet 6 inches at the top with two sides sloping in to give bottom dimensions of 6 feet by 17 feet 6 inches. The two side chambers are 20 by 18 feet at the top with three sides sloping to a bottom 11 by 6. All have a maximum inside depth of 9 feet 2 inches, with the high-water line 7 feet from the bottom. These dimensions give approximate total capacities of 2,450 cubic feet and available dosing volumes of 12,500 gallons for all chambers.

The discharge is through 24-inch Merritt siphons into two 42-inch and one 30-inch conduits to the filters.

Since installed as described above modifications have been made in the method of control of the siphon discharge. Details of these changes are not included, as their effect on the operation of the treatment plant and the efficiency of the processes does not appear to be of sufficient importance to warrant such description.

Trickling filters.—The trickling-filter installation consists of 2½ acres. It should be noted here that the filter installation has a rated capacity of only half that of the Imhoff tanks. The former were designed for an average 5 m. g. d. flow, while the tanks were designed for a 10 m. g. d. flow. It is customary to by-pass around the filters all tank effluent in excess of 5 m. g. d. The details of design for any unit, except for a few minor dimensions, are the same as for the trickling filters at the Intrenchment Creek plant. Reference is here made to that description, note being made of the following differences:

(1) Peachtree filtering material 1½ to 2 inch stone instead of 1½ to 2½ inch.

(2) The distributors are 7 instead of 9 inches below the surface of the stone.

(3) The main collector is 24 inches throughout.

(4) There are three 30-inch outlets to the stream instead of one 42-inch.

Sludge beds.—The sludge-drying area is identical in design and dimensions with that described at the Intrenchment Creek plant. Reference is made to that description.

The sludge-drying area is about one-third sufficient for the plant. A large amount of sludge is discharged on large low-lying flats across the creek. Some is also discharged into the creek at times of high water.

By-passes.—At the inlet manhole to the plant an overflow weir, adjusted to 12 m. g. d. flow, by-passes all above that amount. During heavy storms this weir is pulled and the entire flow by-passed. After passing the grit chambers either the tanks or filters or both can be by-passed, or a portion of the tank effluent can be sent to the filters and the remainder by-passed. This last is, as described above, the normal method of operation.

Laboratory.—All laboratory work for the three plants is done at the Peachtree plant. Here adequate laboratory facilities with sufficient apparatus to perform all necessary analyses are provided.

Residence.—An attractive frame residence is provided at the plant for the superintendent of the three sewage disposal plants.

Miscellaneous.—As originally constructed roughing filters were provided between the tanks and the trickling filters. These devices, however, are not used and for operating purposes are nonexistent.

III. BALTIMORE, MD.

Part of the sewage received at the treatment plant has passed through the screens at the pumping station. It is, however, mixed with unscreened sewage in the outfall sewer.

Screens.—The outfall sewer at the entrance to the treatment plant is 12 feet 3 inches wide by 11 feet high, with rounded top and slightly curved bottom. This discharges into an entrance chamber 18 feet 6 inches long, 12 feet 3 inches wide at the inlet, flaring to 25 feet 6 inches wide at the outlet, and 12 feet deep at the inlet, sloping to 14 feet at the outlet. At the outlet a baffle or column divides the chamber to allow two openings 7 feet wide into the two compartments of the screen chamber. These openings are provided with stop planks.

The screen chamber is 49 feet 3 inches long, 25 feet 6 inches wide, and 14 feet deep. The screens are of the bar type placed nearly parallel to the line of flow. The influent or outside channel for each screen is 10 feet wide at the inlet but narrows to 4 feet at the outlet, as the screens are not exactly parallel with the sides. This arrangement gives a central or effluent channel 5 feet 6 inches wide at the inlet and 15 feet 6 inches at the outlet. The central channel is divided into two equal sections by a middle T shaped wall. Both discharge through stop plank controlled openings into separate chambers from which feed lines lead to the meters.

These chambers are each 23 feet 6 inches long, 12 feet wide, and 14 feet 6 inches deep. They are separated by an 18-inch wall, but connected by two 3-foot 6-inch square openings cut through this wall. It is thus possible to use both sides of the screen chamber to feed the same meters. This screen chamber installation is complete for future growth of the plant.

The screens themselves are 49 feet 6 inches long by 11 feet 7 inches high, but set at a slope to give a vertical height of only 11 feet. They are made of one-half by 1½ inch bars spaced to give a clear opening of seven-eighths inch.

The screens are cleaned by hand, the screenings being raked up to the platform by the top of the central T wall. From here the screenings are taken in a wheelbarrow to a platform just outside the building which covers the screen chamber. Farmers take them away from the platform, paying a fixed price per load. The building covering the screen chamber is of attractive concrete construction, with ventilation through the roof.

Venturi meters.—Feed pipes to the meters are taken off the north chamber only. The openings from the south chamber are blocked pending future enlargement of the treatment plant as a whole.

From the north chamber, five valve controlled 42-inch cast-iron pipes are taken to the meter house, which lies just north of this chamber. Each line feeds a 42 by 21 inch recording Venturi meter. Three of these measure the flow to the three hydrolytic tanks, the fourth the flow to the Imhoff tanks, and the fifth is idle pending further installation.[1]

Hydrolytic tanks.—There are three hydrolytic tanks, each having a total inside length of 417 feet 8 inches.

The sewage from the meter house is taken to the tanks in 42-inch diameter conduits, one for each tank. These enlarge to 6 feet in diameter just before entering the tank at the center of the inlet wall. They discharge against a deflector wall that runs across the tank 3 feet from the end wall. This deflector wall has six 9-foot wide openings spaced on 8-foot centers.

Each tank is divided transversely into two sections separated by a curtain wall which extends up from the bottom 6 feet. Three feet ahead of this wall is a scum or baffle extending down 1 foot below its top.

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[1] One hydrolytic tank and meter has been added subsequent to the survey.

The inlet section is 103 feet 11 inches long by 101 feet 9 inches wide by 10 feet 6 inches to 11 feet 9 inches deep. The bottom slopes into three longitudinal hoppers, each 68 feet 3 inches long, by 28 feet wide at the top and 2 feet wide at the bottom, and 1 foot 3 inches deep. Down the centers of these hoppers 2-foot semicircular bottom drains lead on a 2.75 per cent grade to a 32 by 48 inch sludge drain under the curtain wall.

The outlet section is 313 feet 9 inches long by 101 feet 6 inches wide by 13 feet to 15 feet 6 inches deep. The bottom slopes similarly to that in the inlet section except that there are only two instead of three hoppers. These hoppers are 204 feet 11 inches long at the bottom by 50 feet 9 inches wide at the top and 2 feet wide at the bottom. The drain channels slope from both ends to a cross drain located 54 feet 8 inches nearer the curtain wall than the outlet wall. These cross drains lead to an egg-shaped sludge conduit under the dividing walls between two tanks. The final outlet is through six 24-inch circular sluice gates into an effluent channel 12 feet 6 inches square. Three feet in front of the sluice gates is a scum board extending down 6 inches below the bottom of the gates or 7 feet 6 inches from the top of the tank.

Quite extensive arrangements are provided for flushing the tanks. Along the top of the walls of the tanks there are water mains with flushing hydrants.

The sludge conduits under the curtain wall and those under the dividing walls between two tanks lead to pump wells 7 by 3½ to 4 feet in plan. From these, 10-inch De Laval centrifugal pumps with special impellers, shaft connected to 35-horsepower Fort Wayne motors, pump the sludge to sludge digestion tanks. There are two such pumping installations for the hydrolytic tanks, each designed to serve two tanks.

In operation, two hydrolytic tanks run in parallel, with the third idle. At the time of the survey over 95 per cent of the entire flow was being treated in these tanks. A tank is operated until the analyses show its settling efficiency to be materially below normal when it is shut down and allowed to lie idle for one or more days. The liquor between the scum and sludge is drawn off and pumped to one of the operating tanks, and the sludge and scum remaining is then pumped to sludge digestion tanks. Lack of adequate sludge storage tanks has compelled the operation of the hydrolytic tanks for longer periods than would otherwise be desirable, and this has resulted in the accumulation of very heavy sludge and a dry scum to which it is necessary to add considerable water before it can be pumped.

The capacity of each hydrolytic tank is about 4,000,000 gallons, but all this capacity is not available for sedimentation since the accumulation of scum and sludge reduces the volume. Efforts to determine the detention period by the color or dye method have been successful. It was estimated that the detention period averages from three to three and one-half hours.

Imhoff tanks.—The Imhoff tank installation consists of 28 circular radial flow tanks. They were originally designed for a downward and outward flow, but are being converted to a horizontal and outward flow.

A 42-inch conduit from the meter house supplies all the tanks, which are arranged in two rows of 10 tanks each and a third row of 8 tanks. The conduit discharges into an entrance chamber which flares from 42 inches to 6 feet wide and divides into 5 channels which run between the two 10-tank rows. The two outside channels are 9 inches wide, feeding the first 4 tanks on each side, the next two are 15 inches wide, feeding the second 4 tanks, and the middle channel is 18 inches wide, feeding the last 2 tanks. All are 24 inches deep. For the row of 8 tanks a 26-inch wide channel is taken off the influent chamber, run around a 10-tank row and turned to parallel the far side of the 8 tanks. This 26-inch channel divides into two channels, 9 by 15 inches, each supplying 4 tanks. All channels and all tank inlets are controlled by stop planks.

The inside diameter of the Imhoff tank at the top is 39 feet. The sides are vertical for 3 feet 6 inches. They then slope in on a 1 to 1½ slope to form an 8-inch slot with a baffle wall, to be described later, and continue past the slot to give an 8-inch overlap.

Each tank has a central gas vent, with an inside diameter of 5 feet 4 inches. From this vent the baffle forming the other side and bottom of the flow channel slopes out to meet the insloping outside wall.

Sewage enters the tank from the influent channel by a trough 12 inches wide and 18 inches deep which runs across the tank to a 12 by 16 inch channel circling the gas vent. This originally discharged into the tank through openings in the bottom, but it is being changed to discharge over the channel wall. The flow is, therefore, radial across the tank to a collecting trough 12 inches wide by 20 inches deep, circling the tank, into which the sewage flows over notched weirs. Four feet from the collecting trough a circular galvanized-iron baffle 26 inches deep is hung so that its bottom is about 22 inches below the crest of the notched weirs on the effluent collector.

The effluent collector trough discharges into an effluent channel 3 feet wide and of varying depth. These channels are located diametrically opposite the inlet channels. They lead to and discharge into the effluent conduit from the hydrolytic tanks.

The total depth of the flow chamber from the top of the tank to the apex of the slot is 13 feet 6 inches, but, as the crest of the outlet weirs is 10 inches below the top of the tank, the available depth from the crest of these weirs is 12 feet 8 inches. The designed available capacity is 8,520 cubic feet or 63,900 gallons.

The sludge digestion chamber below the overlap of the slot enlarges from a diameter of 21 feet to 23 feet in a vertical distance of 1 foot 4 inches. The walls are then vertical 5 feet 8 inches to the top of the hoppers. These have a depth of 5 feet 3 inches, the bottoms having a 2 to 1 slope. The sludge outlet is an 8-inch pipe starting over the center of the hopper and sloping up to the top of the tank, passing through the flow chamber. About 5 feet below the flow line a branch is taken off horizontally, and run through the tank wall to discharge into a tile line to the sludge beds.

The capacity of the sludge compartments below the overlap of the slot is 3,612 cubic feet, designed to give a storage of 6 months on a basis of 1 cubic foot per capita for the estimated population of 4,000 to be served by each tank.

At the time of the survey, only 5 of the 28 tanks were operating and these as test units. The tanks, as originally designed, did not give satisfaction. There was considerable foaming and excessive scum formation in the settling chambers in spite of frequent squeegeeing of the walls and sloping bottoms. In addition, when operated in parallel with the hydrolytic tanks, the higher loss of head in the Imhoff tanks and inlet and outlet channels diverted the entire sewage flow through the hydrolytic tanks as soon as the head in the outfall sewer dropped below a certain level, which it did for about four hours each day. When the flow increased, the water level was built up in the hydrolytic tanks and backed from the main effluent channel through Imhoff tank effluent channels into the tanks themselves, stirring up the scum in these tanks.

These tanks were taken out of service in June, 1917, the sewage flow then being too much for one hydrolytic tank and the Imhoff tanks and too little for two hydrolytic tanks with the Imhoff tanks. Several of the Imhoff tanks have been run as test units, and, as a result of these tests, all the tanks are being slightly remodeled. The flow line is being raised to prevent back flow from the effluent channels, the number of weirs on the effluent collecting channel in the tank reduced from 52 to 35 and the flow changed to a horizontal radial direction instead of upward and outward.

Fine screens.—The main effluent channel, carrying the effluent from both the hydrolytic and the Imhoff tanks, discharges into revolving fine screens. These screens were installed to remove solids in the tank effluent which clogged trickling filter nozzles.

Three of these screens were in service at the time of the survey and a fourth was being installed. The original installation consisted of two screens made of cast iron and steel, weighing about 10 tons. Their weight was too much to secure trunnions capable of standing up for more than about 10 days. They were, therefore, abandoned and the present type, designed by Mr. J. J. Neal, adopted. The frames of these screens are made of oak with iron bracing, and they weigh complete only 1½ tons. They are 12 feet in diameter and 10 feet long, covered with 24-mesh Monel metal cloth. Around this cloth a 9 or 10 gauge galvanized-iron wire is wound in spiral.

The sewage enters the inside of the screens, which are set with a horizontal axis of revolution, and flows out through the Monel metal cloth. Cleaning is done at the top point of revolution where a spray of final filter effluent is directed onto the outside of the screen from a 0.008-inch slot in a pipe. The screenings drop into a trough which carries them to an unused Imhoff tank where they are settled.

These screens have proven very efficient, reducing the filter nozzle cleaning from 37 to 141 per cent daily down to 5 to 15 per cent. Each screen can handle over 30 m. g. of sewage daily with a loss of head of 1 to 6 inches. It was stated that the Monel metal cloth lasted about one year, the wire winding about three months, and the screen frame and bearings about five years, when it is necessary to make extensive repairs to moving parts.

Filter-control house.—The effluent from the screens passes to the filter-control house in a covered conduit 12 feet 6 inches wide by 13 feet deep. Here it enters a storage chamber, 48 feet 8 inches long by 25 feet wide by 23 feet deep, through three openings, 5 feet wide by 2 feet 6 inches deep, cut in the common wall between the main effluent channel and the storage well, the bottom of the openings being 5 feet below the floor level above the storage well. These openings were originally equipped with float controlled gates to maintain a constant level in the storage well, but this automatic feature has been abandoned, and the flow into the storage well is now regulated by hand within established limits.

There are twenty 18 by 27 inch cast iron pipes, 10 of which are controlled by 18 by 27 inch sluice gates in the storage well. These are set in the side of the storage opposite the inlet. These are arranged in two batteries, each battery having two rows of 5 pipes each, one above the other. Only one battery is in use as the filter installation does not, as yet, require more than 10 lines, each of which provides for 3 acres.

With the sluice gates from the storage well open, the flow through to the filters is controlled by butterfly valves in the ten 18 by 27 inch lines. These valves are actuated by a motor through friction disks. Just inside the building the 18 by 27 inch cast-iron pipes discharge through increasers into 36-inch concrete conduits to the filters.

Trickling filters.—This installation consists of 10 units of 3 acres each, a total of 30 acres. The ten 36-inch feed lines from the control house are carried down along one end of the filter installation, all cast in one block of concrete. They are arranged in two rows of five each, one row on top of the other. The filters lie in 5-row 2 units each. After two rows have been passed the 36-inch circular conduits are converted into a rectangular shape, 2 feet 6 inches wide by 4 feet deep.

At the center of each row, two feed lines are taken off, one for each filter unit in that row, and carried down the center of the filters in a double gallery, 12 feet 4 inches wide by about 7½ feet high. This gallery is divided by concrete partitions into three sections, the central one, 4 feet 4 inches wide, carrying the feed lines, and the two side ones, each 4 feet wide, for inspection galleries.

From the main distributors in the galleries 6-inch lateral distributors are taken off on 15-foot centers, each supplying 11 nozzles. Some of the laterals are of cast-iron pipe while others are of vitrified terra-cotta pipe incased in concrete. All are supported by small concrete posts, the centers of the laterals being about 2 feet 9 inches below the surface of the stone. Beyond the last nozzle the lateral is reduced to a 3-inch cast-iron line, and extended 6 feet to a flushing gallery, 4 feet wide by 7 feet high, where it terminates in a valve. This provision for flushing was used at first, but the present method is to flush through the end risers by removing the nozzle. By flushing through the valve into the gallery it was found that the sediment splashed back into the small underdrains which vent into the gallery.

The risers for the nozzles are 3-inch cast-iron pipe extending above the stone so that the top of the nozzle is 6 inches above the stone. The filter nozzles are on 15-foot centers, but they are not staggered on adjacent laterals so that the diagonal distance between nozzles on two laterals is about 21 feet 2½ inches.

There are on an average of 583 nozzles for each 3-acre unit. The Mertitt nozzle predominates with 4,630 nozzles as against 1,200 of the Taylor clover-leaf type.

The filtering material consists of 8½ feet of trap rock of 1 to 2½ inch specified size. As is usually the case, however, there is some stone well under the 1-inch size.

For drainage, the concrete bottom of the filter is molded into channels 4 inches deep by 6 inches top width, on 11-inch centers. These run parallel with the distributors and drain with a one-half per cent slope from both the main double gallery and the single flushing gallery to a main drain midway between those galleries. This drain is 3 feet wide by 9 inches deep at its upper end with its bottom sloping on about a 0.3 per cent grade to a depth of 3 feet 4 inches at its lower end, where it discharges into the effluent channel. A manhole is provided at the center of this drain for inspection and flushing.

Over the laterial drains molded in the bottom are laid 10 by 20 inch vitrified plates with 6 by one-half inch slots on 3½-inch centers to form the level bottom upon which the stone is laid.

As will be described later, the water level in the effluent channel raises during part of the day 2 or more feet above that originally intended. This backs the water into the filters, which operate during these periods of high-water level with underdrains and part of the filter stone submerged.

At the present time (1920) the entire installation of 30 acres is not needed to take care of the sewage flow. All beds are ripened and kept in condition by being put into service for a short period every day, but the main load is carried by 12 to 24 acres which are put in or taken out of service to correspond with the variations in flow. The average rate of treatment is about 2.83 m. g. per acre per day.

Trickling filter effluent channel.—This lies along the lower end of the rows of filters, and receives the sewage from the main underdrains of the filters. Where it starts at the outlet of the first filter drain it is 3 feet wide by about 4 feet 10 inches deep. Its bottom slopes at a 0.25 per cent grade, thereby increasing the depth, and the width is gradually increased through the entire length of the filter installation, so that at the end of the filters the channel is 10 feet wide by 8 feet 10 inches deep. Before reaching the secondary sedimentation tanks this depth was originally reduced to 7 feet 8 inches, but later due to friction in the mixing channel, described below, it was necessary to build up the walls 1 foot. This produced the flooding of the filter underdrainage already mentioned.

Disinfection.—It was originally contemplated, when designing the plant, that the filter effluent be disinfected with chlorine. A part of the effluent channel was, therefore, designed to act as a mixing chamber after adding the chemical. Where the effluent channel makes a right-angle turn to the secondary sedimentation tanks its width was increased from 10 to 25 feet for a distance of 144 feet and then narrowed down again to 10 feet. In the wide section, baffle walls divert the sewage from one side to the other four times.

Disinfection has been tried only once since the plant was put in operation, and then only for experimental purposes. Arrangements have been made for by-passing part of the flow around the mixing chamber.

Secondary sedimentation tanks.—There are two secondary sedimentation tanks, each 272 feet long by 290 feet wide, with one side wall on a slope, the other being the vertical division wall between the two tanks. The depth varies from 10 to 12 feet, the bottoms sloping to form two shallow hoppers with central drains running to a pump well in the dividing wall.

The final effluent channel from the filters runs the entire length of one end of the tanks, and was designed to feed into them through seven 24-inch sluice gates, set flush with the bottom of the channel and spaced on 40-foot centers. These have proven inadequate, necessitating the cutting of additional openings through the wall between the channel and the tanks.

The outlet of the tanks is over a weir, extending the full width of the tanks and discharging into a final effluent channel, 10 feet wide by 6 feet 8 inches deep.

The tanks have a total capacity of 760,000 cubic feet each, or nearly 5,700,000 gallons.

Hydroelectric plant.—The effluent from the secondary sedimentation tanks is taken to the power house where it is used to generate electric current used for all purposes over the plant. There is available a head of about 18 feet on two Morgan-Smith water turbines, shaft connected to two 110 kilowatt Fort Wayne generators. In reserve, there is an 85-horsepower (4) cycle Nash gasoline engine. Since 1916 it has always been possible to generate ample power with the turbines. The power generated is used for the sludge pumps, the fine screens, the butterfly valves on the trickling filter feed lines, pumps to provide the water supply and others to pump purified sewage for flushing purposes and general use around the plant.

Final effluent conduits.—From the hydroelectric plant, the final effluent is carried in two 5-foot diameter wood-stave pipes 2,500 feet long extending submerged into Back River.

Sludge digestion tanks.—There are two types of sludge digestion tanks, the rectangular type of which three were built as part of the original installation and one in 1921, and the circular type of which 16 were constructed in 1914 in order to give additional storage space.

Three of the rectangular tanks lie adjacent to the hydrolytic tanks. Each tank is 101 feet 6 inches wide by 138 feet 4 inches long by 13 feet 6 inches to 15 feet 6 inches deep. The bottoms slope from both sides and from two ridges on a 11 to 1 slope to 3 longitudinal drains. They also slope from the two ends on the same 11 to 1 slope to these drains. These drains have a 2 per cent grade to sluice gates which vent into a manhole, from which a 32 by 48 inch egg-shaped drain on a 6.44 per cent grade leads to a pump well at the center of the south wall of the three tanks.

The sludge is pumped from the hydrolytic tanks by pumps which were described in discussing hydrolytic tanks. The pipes are carried on the north wall of the sludge tanks which is also a south wall of a hydrolytic tank. The sludge is discharged on the surface of the digestion tanks.

After digestion the sludge is pumped from the well already mentioned to the sludge beds by a pumping installation identical with that described under the hydrolytic tanks.

As the sludge becomes very heavy in these tanks it is frequently necessary to use considerable flushing water to handle it by the pumps. Each tank has a capacity of about 203,000 cubic feet.

In 1914, 16 additional sludge digestion tanks were installed south of the filters and east of the sludge beds existent at that time.

These tanks have an inside diameter of 38 feet. The walls are vertical to a depth of 15 feet below which there is a conical hopper 9 feet 6 inches deep, making the total depth of the tanks 24 feet 6 inches, and giving a total capacity of 20,600 cubic feet per tank or roughly 330,000 cubic feet for the 16 tanks.

The sludge is pumped to the digestion tanks in a 12-inch line from the hydrolytic tanks. From this line, an 8-inch pipe is taken off for each digestion tank. This pipe enters a tank near the top of the hopper and then turns up to discharge near the center about 8 feet from the top.

Digested sludge is removed by the hydrostatic pressure over the outlet of the tank. An 8-inch line starting about 2 feet above the center of the hopper runs across the tank, passes through the side wall about 10½ feet from the top, and discharges into an open sludge channel 12 inches wide by 18 inches deep, from which it can be drawn off through stop gates on to the sludge beds.

In 1921 another sludge digestion tank was built having a capacity of 232,500 cubic feet. This tank is 150 feet long, and 86 feet wide, inside dimensions. The depth of the tank at the sides is 16 feet 3 inches, and at the center 21 feet 3 inches. The undigested sludge enters at both ends near the bottom through a 12-inch cast-iron pipe. There are 6 manholes along the walls, each with 1 outlet pipe, and 3 inlets placed at different elevations. Each inlet is provided with a 10-inch circular sluice gate. The outlet pipes connect with a rectangular concrete channel 12 inches wide and 18 inches deep through which the sludge flows by gravity to the drying beds. A concrete walkway, 30 inches wide, is provided along the top of the tank in order to facilitate the operation. All of the sludge is removed by gravity to the drying beds.[3]

Sludge beds.—There are four separate sludge bed areas, two of these are used for sludge from the sludge digestion tanks, one for sludge from the Imhoff tanks, and one for sludge from the secondary sedimentation tanks.

The first bed installed was 400 feet long by 100 feet wide. It consisted of 30 inches of sand over about 6 inches of gravel, the gravel, however, thinning out toward the edges of the bed. The 30 inches of sand was considered too much for satisfactory drainage, and the depth has been reduced to about 18 inches. The bottom slopes from both sides toward the center on about a 1 per cent slope which is increased for the last 10 feet nearest the center. On the slopes 4-inch drain tile are laid on 24-foot centers with open joints. These connect into an 8-inch vitrified line running through the center the full length of the bed on a 0.25 per cent grade and discharging into a marshy area south of the plant.

Subsequent to the survey a pumping station has been provided to pump the water which runs off from the sludge placed on the drying beds. This station is provided with two 5-horsepower vertical motors direct connected to two 2-inch centrifugal closed impeller sump pumps, each with a capacity of 160 gallons a minute. The water is pumped through a 4-inch cast-iron main to the effluent channel of the primary sedimentation tanks from which it flows through the trickling filters and the secondary sedimentation tanks. Each pump unit will work automatically.[3]

Sludge is applied to the bed at three points from either the 12-inch line from the rectangular digestion tanks or from a 12 by 18 inch open channel from the circular digestion tanks. It is run down a short concrete chute into a small box with its top level with the bed and from this it floods over the surface.

In 1914 another bed of the same area was built on the other side of the 12-inch feed line. Its area, however, was subdivided into nine beds of different widths, and the bed itself is of a different construction. The sand layer is 4 inches deep and rests on a layer of graded gravel 8 to 11 inches deep, except over trenches where it covers the drains. These drains consist of a 4-inch tile down the center of each bed, starting 12 feet from one end and discharging into a 6 to 8 inch main drain, which runs across all beds 12 feet from the other end. This main drain has a grade of 0.5 per cent and discharges into the 12-inch line already described.

Sludge is applied onto splash plates at the center of one end of the beds from an open channel, 12 inches wide by 18 inches deep, into which the circular digestion tanks discharge. Sludge can also be taken into the channel from the 12-inch line from the rectangular digestion tanks.

These two beds are considered as one area. A second area consists of two beds built in 1914, one on each side of the circular digestion tank installation. These beds are in design similar to the second bed described above. The filtering material and underdrains are the same, but the beds are 468 feet long by 150 feet wide, divided into 18 beds, 26 by 150 feet.

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[3] Comment by the Division Engineer of Sewers, Baltimore, Md.

A third area, also built in 1914, is adjacent to the Imhoff tank installation and is available for these tanks only. This area consists of two beds: One, 404½ feet long by 75 feet wide, divided into 15 beds, 75 feet long by 26 feet wide; and the other, 189 feet long, by 75 feet wide, divided into 7 beds, also 75 by 26 feet.

The material in the bed consists of 4 inches of sand over 8 to 11 inches of graded gravel. The underdrainage is similar to the other beds built in 1914—a central 4-inch drain on a 1 per cent grade discharging into a 6 to 8 inch drain on a 5 per cent grade across all the small beds.

Sludge flows in pipes by gravity from the Imhoff tanks to an open channel along the beds; from this channel it is discharged onto splash plates.

The fourth area is adjacent to and for sludge from the secondary sedimentation tanks. This area is 500 feet long by 150 feet wide, with two subdivisions. The bed consists of 12 inches of sand with no gravel, except over the underdrains which are spaced on 25-foot centers. The drains cross the bed to a ditch outside of and running longitudinal with the bed. Sludge is applied to splash plates at four points from 8-inch lines which are taken off a 12-inch header from the sludge pump.

Along the ends of each row of sludge drying beds there is a permanent 24-gauge industrial track. When a bed is to be cleaned a spur track is laid through the center of the bed and cars are run in on this track.

Sludge disposal.—Some sludge, mostly that from the Imhoff tank beds, is hauled from the beds by farmers, but the bulk of the digestion tank sludge is taken to a drying plant located at the treatment plant.

Sludge drying plant.—Adjacent to the sludge drying beds there is situated a plant where air-dried sludge is heat dried. The sludge is carried in industrial cars, which are drawn by a 3-ton Plymouth locomotive, to the plant and dumped. This sludge ordinarily contains about 65 per cent moisture. From the dump the sludge is shoveled into a drag conveyor which carries it to a Renneberg standard direct-heat dryer 6 feet in diameter and 40 feet long. When new this dryer was specified to dry 16 pounds of 70 per cent sludge to 4 pounds 10 per cent sludge per pound of fuel. From the dryer a conveyor carries the sludge to the screens, the screenings going by conveyor to the bagging hoppers and the tailing to a grinder and back to the screens.

Water supply.—The location of the treatment plant necessitates a private water supply. For general washing and flushing purposes the final plant effluent is pumped to a 100,000-gallon elevated steel tank. Water for drinking and use in the laboratories, etc., is obtained from a 6-inch well 150 feet deep and pumped to a 20,000-gallon steel tank slung under the 100,000-gallon wash-water tank.

Administration building.—This is an attractive concrete building with a basement and two stories. The basement contains a machine shop, storeroom, and heating plant. The first floor contains the general offices, lunch room, and toilets; and the second floor is given over to laboratories and a chemist's office.

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Screens.—Sewage is discharged at the treatment plant from a rectangular 4-foot by 18-inch sewer into the screen chamber. This chamber is 22 feet long, 6 feet wide at the inlet, flaring to 11 feet wide 10 feet from the inlet and retaining this width for the remaining 12 feet. The bottom has a slope of one-half foot, giving depths of 4 feet and 4½ feet at the inlet and outlet, respectively, the inlet being level with the main sewer discharging into it.

At a point 6 feet 3 inches from the inlet an 18-inch wall divides the chamber into two flow channels. Each channel is, therefore, 4 feet 9 inches wide by 15 feet 9 inches long. Stop planks permit diverting the sewage into either or both of these channels. Each channel has a bar screen, one with a clear opening of 1 inch, and the other of three-fourths inch, both being inclined downstream at an angle of 30° to the horizontal. Allowing for the inset into grooves the screens are 4 feet 11½ inches wide and 6 feet 8 inches long. They are cleaned by hand, the screenings being raked up onto a platform.

At the outlet of each channel is a measuring weir and the channels are connected to a chamber in which a float actuates a recording device on a 7-day chart. This recording apparatus is similar to that designed at the Lawrence, Mass., Experiment Station.

Grit chambers.—The screen chambers discharge into grit chambers, one for each screen. These are 40 feet long by 6 feet wide and are 6 feet 8 inches deep over all. Within the channels are hung two metal baffles or vanes, running longitudinally, which can be lowered or raised by lifting rods, thus increasing or decreasing the cross-section of the flow area of the channel. The grit drops through a slot between the vanes into a storage chamber. This design gives a cross-sectional appearance similar to an Imhoff tank, except that the baffles do not overlap. Its specific advantage is to maintain a constant velocity through the chamber by varying the flow section with the volume of flow. Up to the present no use has been made of this feature, due to the relatively constant volume of flow.

The bottoms of the chambers, in which are located drain pipes, slope both ways on a 5 per cent grade, but there are also flat false bottoms over the sloping bottoms. This arrangement is to facilitate drainage when the chamber is ready for cleaning.

Housing for screen and grit chambers.—Both the screen and grit chambers are housed in a substantial brick structure which is vented by a 28-inch iron stack 60 to 70 feet high. This stack is to serve also for a Morse incinerator, which was about to be installed to burn screenings. It was stated that the stack practically eliminated any odor nuisance arising from the screens and grit chambers.

Imhoff tanks.—Leaving the grit chambers the sewage flows into a flume 4 feet wide and 3 feet deep to the Imhoff tanks, the distance from the outlet of the grit chamber to the inlet of the nearest tank being 105 feet and the total length 211 feet.

There are 6 Imhoff tanks in all, but they are arranged in two groups of 3 tanks each. By changing the position of the stop planks or gates at the inlet and outlet ends the sewage may be made to pass through each group with the tanks in parallel or in series. It is also possible to reverse the order of the two outside tanks in each series. This effects the same results as reversing the direction of the flow.

Each tank is, over all, 24 feet wide by 89 feet long by 22 feet 1½ inches deep. The flow chamber is divided into two sections, each 10 feet wide, separated by a central gas vent, 3 feet clear width, running the entire length of the tank, except for sludge wells 2 feet by 3 feet over the center of each hopper. This vent is covered with notched 2-inch planks except where concrete walks are located. An 8-inch pipe connects the two channels near the inlet, thus equalizing head over the sludge chamber.

The inlet of each chamber is a free channel, the outlet, which becomes the inlet of the middle tank when tanks are operated in series, is over weirs, two weirs each 4 feet 8½ inches wide for each flow section of each tank. Two feet from the inlets and outlets are located scum boards, consisting of 2-inch planks laid in slots in the side of the tank, some extending down 1 foot 6 inches below the flow line.

The total depth of the flow chamber to the apex of the slots is 13 feet 4½ inches. The sides of the flow chamber are vertical for a distance of 7 feet 6 inches, where they slope inward at a 1 to 1.175 slope, or an angle of 49½° to form the bottom. The slot at the bottom has a minimum perpendicular opening of 6 inches.

Over the center of each of the 6 hoppers there is a box in the gas vent 3 feet long, 2 feet wide, and 4½ to 6 feet deep, according to the position of the tank at which they are located, the 4½-foot box being at the outlet end and the 6-foot one at the inlet end.

The capacity of each flow chamber is 8,000 cubic feet, giving a total of 720,000 gallons for the 12 flow chambers of the tanks. This capacity was designed to give a three-hour detention for 6 m. g. d.

The sludge chamber has a total depth of 7 feet 7 inches from the overlap of the slot to the bottom of the hoppers. The hoppers, of which there are 6 for each tank, are 2 feet 9 inches deep, 14 feet square at the top and 18 inches square at the bottom. The slope of the bottom is therefore about 2.3 to 1. All hoppers are separated by walls through which a 2 by 2 foot opening is left, the bottom of which is 2 feet above the top of the hopper.

From each hopper an 8-inch cast-iron sludge pipe, with an 8 by 14 inch reducer as the inlet, rises to the sludge wells, already described, in the gas vents. Eight-inch, extra heavy, galvanized, wrought-iron pipes run longitudinally with the tank between these sludge wells, sloping 0.3 foot in 14 feet. The riser pipes from the hoppers are controlled by 8-inch plug valves, the minimum hydraulic head over the valve being 3 feet. In the last sludge well there is provided an 8-inch sluice gate to the flow channel whereby the wrought-iron sludge line can be flushed with the sewage in the tank.

To facilitate moving sludge from the hopper a three-fourths-inch lead water line is run along side of and to the bottom of the sludge pipe, and, in addition, a 1½-inch lead line with one-eighth-inch spray holes at 18-inch centers run around the hopper. The 2-inch feeder line is laid on the top of the tank and is available for general use around the tanks. The sludge compartment of each tank has a capacity below the overlap of the slot of 7,614 cubic feet or about 45,700 cubic feet for the six tanks.

Contact beds.—The effluent from the Imhoff tanks is carried in an effluent channel 4 feet wide by 3 feet 3 inches deep to 16 contact beds. These beds all have an area of one-half acre, but are not all of the same shape. The eight nearest the Imhoff tanks are all 83 feet wide by 221 feet long. The remaining beds become wider and shorter so that the two beds farthest from the tanks are 143 feet wide by 111 feet long.

The filtering material consists of 12 inches of crushed slag, 1½ to 3 inch size, over the bottom around the collecting pipes, above which there is a 5-foot layer of 1 to 1½ inch crushed slag.

The main distributing flume passes through the center of the installation, eight beds on each side of it. The flume itself is 4 feet wide and about 2 feet deep covered with a 4-inch concrete slab. The depth varies slightly at different places as the bottom is given a drop of 0.2 foot.

From the flume, sewage is admitted to the beds through distributing chambers, entrance to which is controlled by hand operated stop plates 4 feet wide. The distributing chambers vary in width from 5 feet 4½ inches to 8 feet 3⅜ inches as the width of the bed increases from 83 feet to 143 feet.

The distributing ducts are 5 feet wide by 2 feet deep by 50 feet long. The bottom is concrete and contains 12 inches of screened clean one-half to 1 inch gravel. The outlet to the beds consists of 6 by 6 inch steel bar screens with one-fourth-inch clear openings set in the sides of the ducts below the gravel fill and on 1 foot 11½ inch centers. At the termination of the main duct the sewage passes over a weir and enters an 18-inch vitrified-tile line laid with loose joints immediately under the surface. This pipe is reduced to a 12-inch line at a point one-quarter of the length of the distributing pipes from the end. The 12-inch line terminates in a 3-foot diameter manhole which extends 1½ feet below the pipe and is used to clean out deposits washed from the pipe. The general location of the distributing system is diagonally across the bed.

Around the main 5-foot distributing ducts are placed 18 inches of the one-half to 1 inch gravel, and around the pipe extension of the duct 4 feet of the same material.

Along one side of the duct is constructed a gravel washing shelf 2 feet 6 inches wide and 6 to 12 inches deep, with the bottom sloping toward the duct, and the whole shelf sloping toward the inlet end of the duct where is located a 4-inch cast-iron pipe to take the wash water to the sludge line from the tank.

In operation, the beds to be used are selected, and the sewage admitted by lifting the stop plates between the main distributing flume and the distributing duct. When the bed is full an alarm bell is rung which is the signal for dropping the stop plates.

The period of detention and discharge of the beds is automatically controlled by a 16-inch siphon, actuated by a timing device. The siphon is set in a concrete chamber 4½ feet by 4½ feet by 8 feet 4 inches deep, and the timing device in an adjacent connecting chamber 4½ by 2½ by 8 feet 4 inches deep.

Sewage is received at the siphon chamber through the collecting trough which runs longitudinally down the center of the bed. This trough is 3 feet wide with a depth varying from 7 inches at the far end to 16 inches at the siphon end. It is covered by loose-laid concrete slabs and the far end is vented. Feeding this main trough, 6-inch channel pipes with loose joints but plugged ends run to the sides of the beds. These lines are laid on 12 to 13 foot centers.

The siphons discharge into a main collecting gallery which is located directly under the distributing flume. It is 4 feet wide and about 6½ feet deep.

Main outlet pipe.—The collecting gallery empties into a short 2 by 4 foot flume which ends in a manhole from which a 36-inch reinforced concrete pipe leads to a check valve manhole on the edge of the creek. The outlet from this manhole to the creek is through a 36-inch cast-iron pipe.

Sludge disposal.—At the time of inspection there were six especially prepared sludge beds in operation. These beds were of similar construction except that three were covered with glass roofs of greenhouse construction. The beds are all 150 feet long by 24 feet wide, giving a total area of approximately one-half acre of which, as stated above, one-fourth acre is under glass.

The filtering material consists of one-half to 1-inch gravel 6 inches deep at the center, feathered out to zero at the sides, by the slope of the bottom. Above the gravel is a 15-inch layer of one-sixty-fourth to one fourth inch sand. The bottom below the gravel is natural ground. It is claimed that the ground water during wet weather rises in the sand, interfering with drying. To remedy this, it has been proposed that a concrete bottom be installed. It would appear, however, that satisfactory results could be obtained by increasing the depth of the filtering material and installing more underdrains.

The sludge is applied by means of a gutter extending 80 feet over the bed. This gutter is 12 inches wide by 9 inches deep and constructed of 2-inch planks. The sludge flows by gravity from the tanks in a 12-inch cast-iron pipe to the center of the sludge bed installation. It is then diverted in a wooden trough 12 inches wide by 9 inches deep, and is discharged onto splash plates at the beginning and end of the trough over the bed. Temporary low plank partition walls have been installed across the beds dividing them in halves.

The underdrainage of the beds consists of a single 6-inch vitrified tile line down the center of the bed. The bottom slopes both ways toward it 6 inches in 12 feet. The 6-inch drains all empty into an 8-inch cemented joint line to the creek.

For cleaning the beds a narrow gauge, 24-inch railroad is run over the center of each bed. The base of the rails is 2½ feet above the top of the sand in the bed. With a car at this elevation the total throw from the beds to the top of the car is 5 to 6 feet, which is too high. The tracks all connect by turntables to a ladder track to the sludge dump.

As these six beds are not adequate to properly take care of the sludge, considerable amounts have been lagooned in hollows and spread broadcast over the land. A sludge well was constructed from which a steam duplex ball valved pump draws suction. This installation has been used to pump to the lagoons and to the fields where the sludge is applied with a hose.

At the time of the inspection five new sludge beds were being prepared to which the sludge was to be pumped. These beds were being constructed by merely removing the top soil, leveling and diking, the natural gravel soil being relied upon to give sufficient drainage without artificial assistance. These five new beds will have a total available area of a little less than 1 acre, or almost twice that of the present beds.

All sludge dried on the beds or lagooned is hauled away by farmers and used on fields.

By-pass.—There is only one point at which it is possible to by-pass sewage received at the plant and that is between the Imhoff tanks and the contact beds. This by-pass is used during the winter months, the beds being idle during that period of the year.

Water supply.—Due to its location, city water is not available at the plant. Water is obtained from a 25-foot drilled well pumped by a standard lift pumping engine made by the Standard Pump & Engine Co., of Akron, Ohio. The water is pumped to a pressure tank for which there is an air compressor. A 4-horsepower gas engine operates the pump.

Laboratory facilities.—There is a laboratory located at the plant but the facilities for work and equipment are inadequate for its proper functioning.

Recent improvements.—Since the survey, it has been reported by City Engineer W. E. Sarver that the following improvements have been made: (1) A boiler house constructed, and two boilers of 45 and 150 horsepower installed therein. (2) A 16-ball-valve sludge pump, Wagner type, provided for pumping wet sludge to fields. (3) A three-fourths kilowatt Delco plant installed for lighting grounds and buildings. (4) A coal mine developed on property adjacent to the plant which had been purchased to settle damage claims.

V. COLUMBUS, OHIO.

All sewage received at the treatment plants has been pumped, some of it twice. At the pumping stations it is passed through sand catchers and bar screens. These have been described in detail in the body of this report under the description of the Columbus survey.

The treatment plant, as it now stands, is an old plant rebuilt, the changes consisting principally in converting septic tanks into Imhoff tanks. There are now three sets of Imhoff tanks, the most northerly one nearest the inlet being called "battery A," the middle set "battery B," and the third or most southerly set "battery C."

Entrance chamber, influent and effluent channels.—The 48-inch force main to the plant enlarges into an oval-shaped covered entrance chamber located at the center of the north end of the "A" tanks. This chamber, at its inlet, is 5½ feet high by 10 feet wide, but narrows down in 13 feet to 5½ feet in diameter, and then divides into two 5½-foot conduits running in opposite directions along the north end of the tanks. These conduits can be controlled by stop gates. The branch running westerly is reduced at once to 24 inches in diameter and then to 20 and 15 inches after the second and third tank inlets have been passed. The easterly branch is continued with its original 5½-foot diameter to the northeast corner of the "A" tanks where it rises into an open channel, 6 feet wide by 4 feet 10 inches deep, which follows the east wall of the "A" tanks to the dividing wall between the "A" and "B" tanks, where it reduces to a 4½-foot width, and continues down the east side of the "B" tanks.

Where the reduction in width takes place, there is an opening in the side, 5 feet wide, controlled by stop planks through which sewage is fed to a 3 foot diameter influent conduit to the "A" or "B" tanks. This conduit is contained in the dividing wall between these two sets of tanks, and, as inlets to tanks are passed, it reduces in size to a final 15-inch diameter.

The 4½-foot influent channel along the east side of the "B" tanks reduces to 3½ feet at the dividing wall between the "B" tanks and "C" tanks, where there is a connection to the influent conduit to the "B" and "C" tanks. This conduit is a duplicate of that contained in the wall between the "A" and "B" tanks.

The 3½-foot influent channel continues paralleling the east wall of the "C" tanks, but separated from them by a tank effluent storage basin, to the southeast corner of this basin where it turns along the south end of this basin and of the "C" tanks, serving as either influent or effluent channel for these tanks.

The influent conduits described along the north end of the "A" tanks, between the "A" and "B" tanks and between the "B" and "C" tanks, feed, through 24-inch sluice gates, influent wells, which connect to channels 2 feet 10 inches to 3 feet wide by about 3 feet 5 inches to 4 feet 10 inches deep, the bottom sloping. The sewage passes into the tank from these channels or from the tanks into these channels over 8-foot weirs, two for each tank.

The arrangement at the south end of the "C" tanks is the same as for the other tanks except that there is no influent conduit or influent wells, only the channel serving either for influent or effluent depending upon the direction of flow in the tanks.

The main effluent channel follows the east side of the tank installation between the tanks and the main influent channel, passing over the influent conduits between the different sets of tanks. It is 4 feet 2 inches to 4 feet 10 inches deep, the bottom sloping, by 3 feet 6 inches to 6 feet 6 inches wide, the width increasing as more tanks feed into it. This channel discharges into the northeast corner of the tank effluent storage basin. The channel along the south end of the "C" tanks, when used for effluent, discharges directly into the main effluent channel to the filters.

Imhoff tanks.—In all there are 22 tanks of this type, all built inside of the septic tanks that composed the original installation. As the septic tanks were not the same in all respects the Imhoff tanks made from them differ. They are, therefore, described separately.

The "A" tanks, of which there are eight, constitute the most northerly set. These tanks are the double flow-chamber type, a central gas vent extending to within 5 to 9 feet of the ends of the tank. The over-all inside dimensions are: Length, 140 feet 8 inches from weir to weir, the last 5 feet on one end, however, not being full depth; width, 26 feet 7 inches; depth, 27 feet 1½ inches. The crest of the weirs is 1 foot 5½ inches below the top of the tank.

Each flow chamber is 11 feet 10½ inches wide by 15 feet 8 inches deep from the top of the tank to the apex of the slot. One side and the gas vents are vertical for 7 feet 11½ inches below the top of the tank at which point they slope in on a 1 to 1.3 slope to an 8-inch clear opening slot with a 10-inch overlap. The other side is the wall of the old septic tank. It is vertical for 2 feet 8 inches. It then slopes in on a 1 to 2¾ slope for a vertical distance of 8 feet 8 inches to the bottom of the old wall and is continued from here on a 1 to 1.3 slope to the slot.

The average sewage capacity of each of the two flow chambers from the crest of the weirs to the apex of the slot is 118,000 gallons. The capacities of the two flow chambers differ slightly due to the slope on the old end wall, but this difference is less than 1 per cent.

There are two scum boards beyond the weirs at both ends of the tank, one 3 feet 2 inches distant from each weir and the other two 19 feet 8 inches and 24 feet distant from the weirs at opposite ends of the tank. These extend down about 11 inches below the crest of the weirs. There are no other baffles.

The digestion chamber extends the full 140 feet 8 inches of the tank length. It is 14 feet 9 inches wide by 8 feet 10 inches deep from the slot overlap to the bottom of the hoppers. The space, 1 foot 7 inches deep, lying between the apex of the slot and the slot overlap is not included.

There are seven hoppers each 18 feet 7 inches long by 14 feet 9 inches wide on the top and 1 foot 6 inches square on the bottom. The depth is 4 feet 4 inches and the slope of the bottom 1.5 and 2 to 1.

Over the ridge between each hopper there is a dividing wall across the entire digestion chamber extending to the top of the gas vents. The two end sections and the three center sections are connected by three openings 3 feet wide by 2 feet high cut in these walls, but these openings are omitted in the walls between the second and third and the fifth and sixth sections.

The capacity of the digestion chamber is 13,500 cubic feet.

The central gas vent is 2 feet 6 inches wide, inside dimensions, and approximately 125 feet long, the two sides being brought together to form points at each end.

Each hopper has an 8-inch cast-iron sludge pipe rising vertically from the center of each to the top of the gas vent where it is capped. Four feet below the flow line an 8-inch horizontal line is taken off at a Y branch and run to a channel in the dividing wall between each set of two tanks. This channel is 2 feet wide and of varying depth, 7 to 11 feet, at different sections of the tank and for different tanks, the bottoms being on a minimum slope of 1.78 per cent and a maximum of 4.17 per cent. These sludge channels in the dividing wall between two tanks of the same type discharge into a collecting channel in the dividing wall between two types of tanks, which drain to a small sludge control chamber 4 feet 9 inches long by 3 feet wide, from which two sluice-gate controlled 12-inch cast-iron pipes lead to the channels along one end of the sludge beds.

The "B" tanks, of which there are eight, lie just south of the "A" tanks. With the exception of the weir to weir length, which is 126 feet 2 inches as against 140 feet 8 inches for the "A" tanks, the dimensions are almost identical, the maximum difference occurring in the width of the flow channel in two tanks out of the eight being only 9 inches, or about 6 per cent. These tanks are not therefore described in detail, reference being made to the description of the "A" tanks with notation of the difference in length, as stated above, which is taken up by the omission of one hopper. The arrangement of the influent wells is also slightly different, but not such as to affect operation.

Because of the shorter length, however, the capacity of the flow chamber and that of the digestion chamber is less for the "B" than the "A" tanks, they being, respectively, 108,000 gallons and 11,700 cubic feet.

The "C" tanks, of which there are six, lie south of the "B" tanks. They are almost identically the same as the "B" tanks, the main difference being in the weir to weir length of 117 feet 10 inches, or 18 inches more than the type "B" tanks. This 18 inches is distributed among the six hoppers, 3 inches to each. The majority of the flow chambers are 12 feet 10½ inches wide; 2 of the 12 are, however, 13 feet 7½ inches, a difference of 9 inches, or about 6 per cent.

The capacity of the flow chamber is about 109,000 gallons, and that of the digestion chamber 11,800 cubic feet.

Drains are provided for all influent wells. These connect to 18 by 18 inch tank drains, by which the tanks can be drawn down to the bottom of the flow chambers. The inlets to these drains are controlled by sluice gates, and they discharge into a large blow-off conduit to the river.

Tank effluent storage basin.—This basin lies on the east side of the "C" tanks, occupying a space equivalent to two Imhoff tanks. It is a large effluent well into which all the Imhoff tank effluents are received and passed on to the filters.

The over-all inside dimensions of this tank are: Length, 126 feet 6 inches; width, 56 feet 9 inches; depth, 5.feet 11½ inches, sloping to 8 feet 5¼ inches.

The bottom consists of two rows of five hoppers, each 2 feet 6 inches deep and 28 feet by 25 feet to 28 feet 9 inches by 25 feet 4 inches on the top. From the center of these hoppers, 24-inch diameter openings outlet into effluent conduits under the center of each row of hoppers. These conduits increase in diameter from 2 feet 6 inches at the most northerly, or first hopper, to 4 feet at the fourth hopper. They retain this diameter to the south wall, which contains a 5-foot 6-inch main effluent conduit into which they discharge and which leads to the trickling filter control house.

Control house for trickling filters.—The 5-foot 6-inch effluent channel from the tank effluent storage basin passes under the filters to the control house. This is a two-story circular brick building built over the distributing and collecting wells. All control valves are on the first floor, the second being used for laboratory offices, toilets, etc.

The construction under the building consists of three concentric wells, 24 feet 3 to 9 inches deep. The tank effluent flows into the center well, which is 15 feet in diameter. As this fills the depth of sewage is shown on a float gauge on the operating floor. When the proper level is reached, two 42 by 42 inch sluice gates are opened by hand on the operating floor. The bottom of this sluice gate is 9 feet 9 inches below an overflow in the wall of this well into the next outside well. There is thus an available storage above the outlet, which is practically filter surface level, of about 13,000 gallons.

The outlet sluice gates are left open till the gauge shows the level at or near the bottom of the gates, when they are closed. These gates open into the second well, which is an annular ring 3 feet wide around the central influent well. This well is the distributing well, feeding 12 chambers through 24 by 36 inch sluice gates. These chambers are located in the effluent well and from them 30-inch main distributors lead to the trickling filters, one distributor for each unit. As, however, only eight filter units are installed, four distributors are idle. In operation the 24 by 36 inch gates from the distributing well to the main filter distributors are left open all the time, and control is maintained by the two 42 by 42 inch gates from the influent well to the distributing well.

The distributing well is also connected through six 24-inch sluice-gate-controlled pipes to the receiving chambers of the filter-collecting system, one chamber for each two filter units. These chambers discharge into the main effluent well.

The effluent well is an annular ring 4 feet wide around the distributing well. The distributing chambers, described above, are contained in the upper part of this well, leaving a space 8 feet 2 to 4 inches deep below them for the filter effluent. The main collecting drains from the filters discharge into chambers lying just outside this well, each chamber serving two filters, and these chambers outlet into the effluent well through 24 by 36 inch sluice gates. The effluent well discharges through a 66-inch conduit to the Scioto River.

Trickling filters.—There are eight trickling-filter units of 1¼ acres each. They are arranged in four equilateral triangles, radiating from the control house with a common apex at its center. Each triangle contains two filters, though there is no dividing wall between the two.

An individual unit is therefore a right triangle with a base 252 feet 7 inches and an altitude of 437 feet 5 inches, the control house occupying 19 feet at the apex.

The filtering material is crushed limestone. All filters have 10 inches of 3 to 4 inch stone at the bottom around the underdrains, and 4 feet 6 inches of 1½ to 3 or 1 to 3 inch stone above the 10-inch layer. One-half of the filters have the 1½ to 3 inch stone and the other half the 1 to 3 inch. These are the specified sizes, but much of the surface stone has disintegrated so that there is considerable small stone at or near the surface.

The main distributor, 30 inches in diameter, runs through the filtering material from the control house to the middle point of the base of the triangle containing the filter. Here is provided a connection to a 10-inch water main for flushing. Some few risers are taken directly from this main distributor, but the majority are on 5 and 6 inch laterals, which are taken off the main distributor on 13-foot 3⅝-inch centers and run parallel to the base of the filter. The laterals are terra-cotta pipe encased in concrete and lie about 3 feet 6 inches below the surface of the filter. The risers are 3-inch cast iron. Originally the nozzles, Columbus type, were screwed into the risers, but these are being replaced by the modified Columbus nozzle, which fits on the riser with a quarter turn. On the laterals themselves the nozzles are spaced on 15-foot

4-inch centers, staggered on alternate laterals to give a uniform spacing between all nozzles.

The main collectors start at the base of the filter, one-quarter distance from each end. These have 12-inch radius semicircular bottoms molded in the filter floor. One runs perpendicular to the base and the other parallel to the hypotenuse side of the filter, so that they meet at a manhole at the center of the filter. From this manhole an 18-inch radius drain leads to a manhole on the dividing line between two filters, about 53 feet from the control house. Here the corresponding drain from the other filter is also received and the two are continued to the control house in two parallel drains of the same size as those entering the manhole—that is, 18-inch semicircular bottom. The depth of all the drains vary because of the slope they maintain, the least depth at the start of the 12-inch drain being 18 inches and the maximum depth of the 18-inch drains where they enter the control house being 2 feet 3 inches. The drains are all covered by concrete slabs resting on the lateral underdrains. At the ends of the two 12-inch collectors water connections for flushing are provided.

The lateral collectors are 6-inch half-round tile of special construction laid over the entire bottom of the filter parallel to the base and on 8½-inch centers. These follow the slope of the bottoms, 1.62 per cent, in both directions from ridges to the main collectors.

Secondary sedimentation tanks.—Two secondary sedimentation tanks were included in the original installation. These are 11½ feet deep, but only 4½ feet is available for sewage. In plan they are 307 feet wide on the top, the sides sloping on a 1 to 3 slope to a bottom width of 247 feet, by 240 feet long at one side and 340 feet at the other. The inlet is through fifteen 21-inch vitrified pipes from a branch of the main effluent conduit to the river, and the outlet is over a weir at one corner. Only the bottom is concreted, the sides being natural ground. One of these basins has been materially modified. The changes are not given here, as difficulties in cleaning interfered with their normal operation to such an extent that they are no longer used, the filter effluent passing by them direct to the river.

Sludge beds.—There are 8 beds each 41 feet 6 inches wide by 195 to 315 feet long, 4 having the full length of 315 feet. The total area is slightly less than 2 acres. Each bed has two narrow-gauge tracks on 10-foot 4½-inch centers, the base of the rails being laid flush with the surface of the bed.

The bottoms are laid on a 3 per cent slope from the center and two sides to two 3-inch tile drains laid on a 1 per cent slope in the channels. They discharge into two 8-inch drains which run across the beds one-quarter distance from each end and lead to the trickling filter collecting system.

The filtering material consists of 1 inch of sand, 2 inches of one-sixteenth to one-fourth inch stone, 2 inches of one-fourth to three-fourths inch and 3 to 7 inches of three-fourths to 2 inch stone.

The sludge is discharged onto splash plates at one end of the beds. In cleaning, cars are run onto the beds by a gasoline locomotive and hauled away when loaded to a dump on the inside of a levee along the Scioto River.

Laboratory facilities.—As already stated the laboratory is located on the second floor of the control house. The laboratory rooms are adequate, with ample equipment for all necessary work.

VI. FITCHBURG, MASS.

Sewage treatment at Fitchburg, Mass., starts before the sewage reaches the treatment plant proper. The main interceptor carrying the bulk of the city's sewage discharges into grit chambers located somewhat over a mile from the plant.

Main grit chambers.—This installation originally consisted of one chamber 18 feet wide by 53 feet 9 inches long. The extreme width of 18 feet obtained for only about one-third of the length, the sides contracting toward the inlet and outlet. The bottom was nearly flat, except at the center, where there was a V trough with its bottom opening into a storage chamber 31 feet 6 inches long, 8 feet wide, and about 8 feet deep. This was cleaned through manholes, the supernatant liquor being pumped out by a 4-inch centrifugal pump.

Since installed, this chamber has been modified by a central partition wall dividing the large channel into two smaller ones. By inserting new end walls with gates the total length of the grit chambers proper are reduced, the constricted inlet and outlet channels being used in common by the two new chambers. By this arrangement one chamber can be cleaned while the other is in use.

Siphon.—From the grit chamber the sewage passes through a 48-inch sewer to the siphon entrance, a distance of about one-third of a mile. This siphon, inverted type, consists of a 30-inch cast-iron pipe approximately 1 mile long.

At the entrance chamber to the siphon is located an inclined bar screen with 1¼-inch openings. This is cleaned by hand twice a day.

Low-level pump station.—The sewage system of South Fitchburg is too low to enter the inverted siphon by gravity. It is, therefore, collected at a point on the siphon about one-quarter mile from the treatment plant and pumped into the siphon. Before reaching the suction of the pumps, the sewage first passes through a bar screen with three-fourth-inch openings and then over a sump, which serves as a grit chamber.

The pumping equipment consists of two 4-inch American Well Works centrifugal pumps, shaft connected with flexible joint to two 10-horsepower Western Electric motors. They operate automatically by float-controlled starting and stopping devices, and pump against a head of about 65 feet. One pump is in operation practically continuously, the other being thrown into service only when the flow exceeds the capacity of the one in use.

Measuring device.—The 30-inch siphon discharges through a 30 by 15 inch integrating recording Venturi meter.

Imhoff tanks.—Primary sedimentation takes place in five Imhoff tanks. These receive the sewage direct from the Venturi meter and under the residual pressure from the inverted siphon. The inlet conduit is a 30-inch pipe with three 12-inch sluice-gate openings into the flow chamber of each tank. Both ends of the tank are identical, thus permitting the reversal of the direction of the flow in the tanks.

The outlet channels, one at each end of the tanks, are 3 feet 6 inches wide by 4 feet deep. They receive the sewage over outlet weirs extending over all except three 18-inch sections on each tank and discharge into the trickling filter dosing tanks.

At the time of inspection, June, 1920, four tanks were being used regularly as sedimentation tanks; the fifth was reserved largely for digestion of sludge from the secondary tanks, being, however, used as a primary tank if one of the other four had to be thrown out of service.

The tanks themselves are 90 feet long, 30 feet wide, with a total depth of 25 feet 11 inches. The flow line is about 1½ feet below the top of the tank, the exact distance being determined by the elevation of the adjustable outlet weirs.

The flow chamber proper is 26 feet wide by 90 feet long. The sides are vertical for a depth of 8 feet 6 inches where they start to slope inward on a 1 to 1½ slope to form the bottom and traps. The bottom of the chamber is of a saw-tooth shape, there being two inverted V partitions dividing the lower sections of the tank into three channels averaging 8 feet 8 inches wide at the top. The two inverted V partitions form with each other and with the two sloping sides three slots, one at the bottom of each channel. These slots have a slant opening of 6 inches, or a horizontal opening of a little over 6½ inches, and a trap overlap of 3 inches.

The bottom as well as the gas chimneys were constructed of rib metal reinforcing lath plastered with 2 inches of 1:2 concrete. This construction has not proven satisfactory. Several chimneys have failed and had to be replaced, the replacements being of plastered brick construction, and the bottom baffles have sprung between points of support, causing the slots to be uneven width.

Two gas vents, each 2 feet wide, run the entire length of the tank along the sides. In addition there are six chimney vents 2 feet wide by 9 feet long, venting the two inverted V's at three points directly over the lowest points of the sludge hoppers. The area of all vents is 17 per cent of the total area of the tank.

There are scum boards at each end extending down about 20 inches, but no baffles. Each flow chamber has an available capacity of about 24,000 cubic feet or 180,000 gallons.

The main walls of the tank are vertical for a distance of 18 feet 5 inches, where the bottom hoppers start. There are three square hoppers in each tank, each 30 by 30 feet in plan at the top, sloping down 7 feet 6 inches on a 2 to 1 slope to the bottom. There are no partitions or baffles between the hoppers.

Each hopper has an 8-inch cast-iron sludge outlet pipe rising vertically from directly under the center of one of the gas vents. This places it off center in transverse section, but over the center in the longitudinal section. Eight and a half feet above the tank it connects with a 10-inch horizontal riveted steel pipe through which it flows by gravity to the sludge beds. As the sludge beds are at a higher elevation than the surface of the sewage in the tank, it is necessary to lift the sludge to the beds. This is done by an air lift, the air being furnished through a 2-inch line entering the sludge pipe about 6 feet from its foot, by a Rix Gardner Air Compressor No. XD80, belt connected to a 10-horsepower Westinghouse motor. This installation is located in the basement of the administration and laboratory building.

No water connections have been provided to the hoppers. Below the overlap of the slots there is a total sludge digestion space of 13,000 cubic feet.

Siphon dosing tanks.—The effluent from the Imhoff tanks is discharged into the trickling filter dosing tanks. These tanks are arranged to receive and discharge alternately and are operated by air controlled Merritt automatic alternating 30-inch siphons.

The tanks in plan at the full-water level are each 32 feet 2¾ inches by 35 feet 3¾ inches. Three sides of each tank are vertical construction while the fourth side combined with the bottom of the tank is irregular in shape, so designed as to create a uniform distribution of sewage over all portions of the filter. The total capacity of No. 1 tank is 53,765 gallons of which 47,161 gallons are discharged. The capacity of No. 2 tank is 57,814 gallons of which 50,391 gallons are discharged. The difference in capacity is due to the fact that the inlet weir of No. 2 tank is 0.47 of a foot higher than the inlet weir of No. 1 tank.

Trickling filter.—From the dosing tanks the sewage flows through a 36-inch cast-iron pipe to the trickling filter. This filter is rectangular with an effective area 405 by 223 feet or 2.1 acres.

The distributors run lengthwise with the filters spaced on 13-foot centers, and consist of 17 lines of 16-inch cast-iron pipe which are reduced to 12-inch over the extreme half of the filter. These distributors supported entirely by the filtering stone are laid at or just below the surface so that the nozzles are screwed directly into them and all risers thus eliminated. Each line is controlled by a separate 14-inch gate valve, making it possible to throw out of service any individual line without affecting the others. Inspection hatches are provided at each end of each line and at the reducers. There is a 6-inch blow-off valve at the extreme end of each line for flushing purposes.

There are 467 filter nozzles spaced every 15 feet on the distributors and staggered on alternate lines. The nozzle used is the modified Worcester type.

The drainage system on the filter bottom consists of troughs or channels having 11-inch top width and 3-inch depths. They are spaced 15 inches center to center, which gives 4-inch flat ridges between them. The channels slope from the central gallery (see below) toward the sides, at a grade of 6 inches in 106 feet, and discharge into two effluent channels, one of which is 21 and the other 30 inches, the latter being used also as a by-pass conduit. Both discharge into a 30-inch conduit to the secondary sedimentation tanks.

Above the channels, resting on the ridges, are laid concrete blocks, 17 inches long, 1½ inches thick, and 4 inches deep. The blocks on adjacent channels thus overlap 2 inches on each ridge. This construction gives about 33 per cent air space. Over the blocks is laid a layer of 3-inch cobblestones, and over these 10 feet of 1 to 2 inch broken trap and granite rock.

Through the longitudinal center of the filter is located a flushing gallery 4 feet wide and 6 feet high, inside dimensions, with a horseshoe-shaped arch roof. The bottom is 2 feet 5 inches below the filter bottom, and the top is covered by 6 feet 7 inches of filter stone. All the grooves of the filter bottom open into and slope away from this gallery. From it, therefore, ready inspection can be made of the drainage system. A 6-inch water connection to the gallery affords ample flushing facilities for cleaning the underdrains. Any stoppage in a drain is at once evidenced by back flow into the gallery.

Secondary sedimentation tanks.—A 30-inch concrete conduit carries the effluent from the filters to the secondary tanks. This conduit is provided with an overflow weir 25 feet long, with its crest 10 inches above the weirs on the secondary tanks and 8 inches below the top of these tanks. Thus any possible danger of flooding the tanks is eliminated.

The secondary sedimentation tank installation consists of four circular tanks of the Dortmund type. They have an inside diameter of 30 feet and a total depth of 24 feet, of which 14 feet 9 inches is vertical and 9 feet 3 inches is in the hopper bottom. The flow line or crest of the outlet weirs is 18 inches below the top of the tank.

The sewage is carried to the center of the tank in a 16-inch spiral riveted pipe and discharged into a vertical pipe made of ¼-inch boiler plate, 5 feet in diameter and 12 feet long. The point of discharge of this pipe is 12 feet 4 inches below the top of the tank or 10 feet 10 inches below the flow line. From there the sewage flows upward and outward radially to twenty-four 2-foot outlet weirs on the effluent collecting channel, which is located within and at the outer circumference of the tank. From this the effluent flows down a flight of concrete steps to the final effluent channel to the river.

The hopper, which underlies the entire tank, is 30 feet in diameter at the top and 2 feet 3 inches at the bottom. The sides have a slope of 1.4 to 1.

The sludge from these tanks is pumped into an Imhoff tank used as a digestion tank for this sludge. The outlet sludge pipes, which are 6-inch cast iron, run to a small pump house located close to the tanks. The pump, a 4-inch Epping-Carpenter centrifugal, shaft connected to a 15-horsepower Westinghouse motor, draws direct from any of the tank hoppers through a short suction into which all the sludge lines are connected but separated by gate valves.

The sewage inlet flume to the tanks acts as an inlet scum board. There are no other baffles of any nature in the tank.

The total capacity of each tank is 12,750 cubic feet. The capacity from the flow line to the bottom of the vertical inlet flume is 7,600 cubic feet or 57,000 gallons. This figure probably represents fairly closely the settling capacity of the tank. The remainder of the tank has 3,990 cubic feet, of which 2,280 cubic feet are in the hopper itself.

Sludge beds.—The original plant included 11 sludge beds, each 15 feet wide and 111 feet long, giving an area of about 0.42 acre. These are located adjacent to the Imhoff tanks but about 3 feet higher in elevation. The dividing walls consist of 2 by 12 inch plank. The bed itself consists of 6 to 8 inches of sand having an effective size of 0.15 mm. and a uniformity coefficient not exceeding 10. No underdrainage is provided because of the porous nature of the natural soil. Each bed has a narrow-gauge track, with ties laid flush with the surface of the sand. As these beds have proven inadequate use is made of some low lying area near the plant for disposal of sludge by lagooning. This area is known as beds Nos. 12 and 13, and contains about 2 acres.

Administration building.—This building is of attractive brick construction consisting of a main floor and basement, which, however, has a ground level entrance at the rear. The main floor contains the office and a chemical and a bacteriological laboratory. Both are well equipped and in the hands of a competent laboratory man, who is in charge of the operation of the plant. The basement contains a pump room for the sludge air lift, a locker room with shower and toilet facilities for the men, and general storage space.

By-passes and overflows.—The main by-pass for the entire plant is the blow-off valve on the inverted siphon where it crosses under the river. Even after passing through the meter at the plant the sewage can be by-passed. The effluent from the Imhoff tanks can be sent around the filters, and there is an overflow in the siphon chamber to take care of excessive flows. The effluent channel from the filters to the secondary tanks has an overflow weir, by which it would be feasible to by-pass the secondary tanks.

VII. HOUSTON, TEX.

A. NORTH SIDE PLANT.

Treatment of sewage tributary to the north side plant at Houston starts before it reaches the plant. The Willow Street pumping station, located in the center of the city, receives sewage from sewers high enough to discharge by gravity and also from three sections served by pumps. For one of these sections a 250-gallon Simplex ejector was being installed in August, 1920, to take the flow from a relatively small area. The other two areas are larger; one is served by two 4-inch Swaby centrifugal pumps, which operate intermittently, emptying a 15,000-gallon collection well. At this station the sewage is made to pass a screen with one-half inch clear openings as a protection for the pump. The third station has a 5-inch Buffalo centrifugal pump operating continuously, with a 500-gallon Simplex ejector to take peak loads. The pump at this station also is protected by a screen.

At the Willow Street pumping station the sewage is passed through screens and grit chambers and pumped by three 16-inch Gould centrifugal pumps to a 42-inch circular sewer to the treatment plant.

Screens.—Sewage enters the pumping station through a 36-inch gravity sewer which discharges into a manhole 6 by 8 by 10 feet deep. From this it can be by-passed direct to White Oaks Bayou or discharged through a short 3 by 3 foot connection into the screen chamber which is 16 feet long, 6 feet wide and 6½ to 7 feet deep. The screen itself, made of one-half by 2½ inch bars with 1 inch clear openings, spans the entire width of 6 feet and is 10 feet 5⅝ inches long, inclined downstream at an angle of about 18° to the horizontal. Cleaning is done by hand, the screenings being raked to a concrete platform at the top, from which they are carted to the city garbage incinerator near by and burned.

On one side of the screen there is an adjustable weir over which sewage is by-passed to an overflow chamber when the head on the screen is about 3 feet. This chamber is 10 feet long, 2 to 3 feet wide and 3½ sloping to 4½ feet deep. It discharges through a 24-inch pipe to White Oak Bayou.

Grit chambers.—The screen chamber widens at its outlet into the grit chambers of which there are two, each controlled by handwheel-operated sluice gates at both ends.

The chambers are 60 feet long by 6 feet wide. The bottom is constructed with three hoppers 9 inches deep, giving a total depth of 4 feet 9 inches at the top of the hoppers and 5 feet 6 inches at the bottom. From the bottom of each hopper an 8-inch pipe, controlled by a mud valve, connects through two 10 and a 12 inch pipe to White Oak Bayou. It is through these pipes that the chambers are cleaned, the deposits being flushed into the bayou.

The grit chambers discharge through a 36-inch pipe into the suction channels of the pumps by which the sewage is lifted to a 42-inch circular gravity sewer to the treatment plant.

Plant inlet.—The 42-inch sewer line discharges into an entrance chamber from which it can be drawn into any of four 2½ foot wide by 4 foot deep channels, which lead to 4 aeration tanks; or it can be turned down and under the chamber through a 1½ by 4 foot orifice into a 48-inch by-pass, which discharges immediately into a 36-inch sewer to the Buffalo River. All these openings are controlled by handwheel-operated sluice gates.

Aeration tanks.—Sewage enters the continuous flow aeration tanks through an opening 4 feet deep and 10 feet wide, formed by simply cutting out the dividing wall between the influent channel and tank.

In all, there are four complete aeration units, consisting of an aeration and a reaeration tank, each unit the same as all others with the exception of the side upon which the reaeration tank is located. On either side of the center line of the installation there is a reaeration tank, then two aeration tanks and finally another reaeration tank.

Each aeration tank is 280 feet long, 18 feet wide and 10 feet 9 inches deep from the top of the tank to the top of the filtros plates at the bottom.

The bottom of the tank consists of ridges and channels across the tank. The ridges occur every 5 feet and, in section, are isosceles triangles with a base of 3 feet 10 inches and an altitude of 1 foot 9 inches. This leaves across the tank flat channels 1 foot 2 inches wide, with bottoms 3 inches below the base of the triangular ridges to receive the filtros plates.

There are 12 of these plates, each 12 by 12 by 1½ inches, in each channel. They were originally cemented with sulphur into cast-iron holders, 6 plates to a holder, to which the air pipes were connected. It was believed that the action of the sewage on the cast iron formed a sufficient amount of rust or iron hydrate to clog the plates badly. Whether the clogging was due to this cause or not, there was no question about their being clogged. All holders were, therefore, removed, the plates chiseled out, and subjected to an acid bath, after which they were replaced in the tank, but this time in concrete holders, and grouted in place.

At the inlet end of the tank an 8-inch cast-iron pipe leads to the sludge pumps and at the outlet a 12-inch line to drain the tank for cleaning, repairs, or when out of service for any length of time. A 6-inch channel down the center of the tank for its entire length, cutting all ridges, leads to this pipe and enables complete emptying of the tank. There are no baffles.

The outlet of the tank is an 18 by 48 inch sluice gate, located at one corner of the outlet end. This connects to a channel 4 feet 4 inches wide by 10 feet 9 inches deep with filtros plates in the hopper-shaped bottom of the channel. Adjacent tanks discharge into the same channel, and sewage is taken off from both sides to rows of sedimentation tanks.

Air distribution system.—Supported on the top of each tank and running down the center for the full length, is the main feeder pipe. This is a 12-inch line for 140 feet, 10-inch for 56 feet, 8-inch for 56 feet, and 6-inch for the remaining 28 feet. Spaced every 56 feet, beginning 28 feet from the inlet, a 6-inch and a 4-inch lateral are taken off the main feeder, these distribute air to three 4-inch lines which run the entire length of the tank and connect by 2-inch drops with the aerator plates. The 4-inch lateral from the main feed line supplies one of these 4-inch lines serving one row of plates in the main aeration tank, but the 6-inch lateral after supplying one 4-inch line for a row in the main aeration tank is extended by a 4-inch pipe to a second 4-inch line serving the plates in the sludge reaeration tank. From the end of the aeration tank a 4-inch line is carried down the center of the effluent channel and connected by drops to its plates to prevent sludge deposition before the sewage enters the secondary sedimentation tanks; and this 4-inch line is carried down the center of the sedimentation tank for sludge removal by air lift. A third 4-inch line is carried down that section of the reaeration tank adjacent to the secondary sedimentation tanks.

All the 2-inch drop lines to the filtros plates contain disks of canton flannel to filter the air.

Sedimentation tanks.—For each aeration unit 10 sedimentation tanks are provided. These are operated in parallel. The direction of flow in the sedimentation tanks is perpendicular to that in the aeration tanks.

The influent channel of these tanks is the effluent channel of the aeration tanks, already described. The inlet is through a submerged opening, 18 inches deep by 9 feet long, the bottom of which is 9 feet 2 inches from the top of the tank, or just at the top of the hopper channel containing the filtros plates of the influent channel. Control is exercised by flap gates operated from the top by a lever combination. These are, as a rule, set at an angle of about 45° and thus act as downward baffles. There are no other baffles in the tank.

The tanks themselves are 10 feet wide by 18 feet 10 inches long and 22 feet 10 inches deep. The two end walls are vertical for a distance of 9 feet 7 inches, at which point they slope on an approximate 1½ to 1 slope, to a 3½ by 3½ foot bottom. The side walls have vertical depths of 17 feet 3 inches where they start sloping in on practically the same slope as the end walls to the bottom. The crest of the outlet weir is 1 foot 3 inches below the top of the tank.

In the center of each tank is suspended an 8-inch cast-iron sludge pipe. This reaches down to within a few inches of the bottom of the tank and terminates in a special flared mouthpiece. Near the top a horizontal 8-inch line to the reaerating channel is connected by a T. A four-pronged stirring device, operated by a rod through the center of the 8-inch sludge pipe serves to loosen the heavy sludge around the mouth of the pipe. Sludge is removed by an air lift, a 1-inch line entering the sludge pipe about 11 feet below the top of the tank. The sludge removal schedule is different at the two plants. At the south side plant it is customary to remove intermittently, the air being turned into the sludge pipe for a definite period and then shut off. A continuous flow of sludge is obtained by rotating tanks. At the north side plant a small hole is drilled through the valves on the air lines. The valve is kept closed at all times, but the air passes continuously through the drilled hole.

The outlet from the sedimentation tank is over two 3-foot weirs into channels 2 feet 4 inches wide by 4 feet 3 inches deep, one for each row of tanks. These all connect to an effluent-collecting chamber, discharge from which is also over weirs. It is at this point that the flow is measured by a gauge recording the depth of flow over the weirs.

At the north side plant wooden troughs with 1-inch holes bored in the bottom have been set across the tanks. These are connected by 2-inch pipe siphons over the effluent weirs into the effluent channel. It was claimed that the velocity over the weirs without these siphons had been sufficient to cause currents which pulled up sludge and carried it into the effluent channel. The siphons corrected this by reducing the flow over the weirs. These troughs, however, have not been needed and have never been placed in the south side plant.

Sludge-reaeration tanks.—These tanks, one for each aeration tank, run the entire length of a complete unit of aeration and sedimentation tanks. They are in two sections. The first, a collecting channel, paralleling the sedimentation tanks, though separated from them by the effluent channel, is 104 feet 6 inches long by 3 feet 6 inches wide by 10 feet 9 inches deep. The bottom is hoppered and has one longitudinal row of filtros plates. This channel receives the sludge from the 8-inch sludge lines in the sedimentation tanks. Where the sedimentation tank and the aeration tank join, the sludge passes from this channel through an 18 by 48 inch sluice gate into the second section of the reaeration tank, which is 280 feet long, 9 feet wide, and 10 feet 9 inches deep. This section parallels and is adjacent to the aeration tank, and discharges into it at one side of the inlet end through an 18 by 48 inch submerged opening. Filtros plates are set in rows of 6 plates across the reaeration tank, the rows spaced 5 feet apart as in the aeration tank. The 6-inch channel for draining is also provided as in the aeration tank. The entire construction including bottom details is the same as for the aeration tanks, the only difference being that it is only half as wide.

An 8 inch sludge pipe to the sludge pumps is provided at the outlet end of the reaeration tank at the inlet end of the plant. In addition, the narrow section of the reaeration tank, is connected to the 12-inch line into which the aeration tanks are drained when it is desired to empty them. These connect to the main effluent pipe to Buffalo River.

Power house.—The power house is a brick building 72 feet long by 24 feet wide (inside dimensions). Adjoining it, with a common dividing wall, is the air screen chamber, 16 by 32 feet. The air screens consist of panels of 8-ounce duck backed by canton flannel. These panels, having a total area of about 700 square feet, are arranged on 8 diagonals, forming four V's across the 32-foot dimension, but occupying only 9 feet of the 16-foot dimension. The other 7 feet are taken up by baffle walls to two 20-inch-diameter suctions for the blowers. Air is drawn in through 5 shuttered or louvered openings, 6 by 3 feet, in the outside walls.

Air is pumped by three Sturtevant No. 10 blowers, rated at 19.7 cubic feet of free air per revolution, 3,750 feet per minute at 205 revolutions. The blowers are gear connected to two 150-horsepower constant speed General Electric Co. motors and one 150-horsepower, 2 speed standard oil engine. All blowers connect to a 16-inch header which discharges through a 20-inch supply line. This divides into two 16-inch lines running along the inlet end of the aeration tanks. After two of the main feed lines over the aeration tanks have been taken off, the 16-inch header is reduced to 12 inches and supplies the main feed lines to the two outside aeration tanks. All four main feed lines are metered. Description has already been given covering the air system over the tanks.

The power house also contains a 6 inch special design Worthington volute centrifugal pump direct connected to a 10-horsepower General Electric Co. motor for pumping sludge.

Sludge disposal.—At the present time, and for the past two years excess sludge has been pumped to 3 lagoons, each of about 10,400 cubic yards capacity. The sludge is allowed to settle and the supernatant run back to the aeration tanks. At the time inspection was made, the midle of August, 1920, there was capacity left in these lagoons to take care of sludge for about 6 months longer. It was expected by that time to have the drying plant in operation.

This drying plant can best be described by taking up the various processes involved in the order in which they occur. From the sewage tanks the sludge is pumped to three elevated 50,000-gallon wooden tanks. Here it is allowed to settle and the supernatant drawn off. The settling period is limited by the fact that sludge quickly turns septic and in this condition is not suitable for pressing. The sludge in these tanks is supposed to be reduced from 99½ to 98 per cent moisture.

From the settling tanks the sludge runs by gravity to two 500-gallon Simplex ejectors operated by two Gardner compressors driven by 20-horsepower motors. The ejectors discharge into two 120-plate Simplex presses, which, it is anticipated, will operate under 100 to 120 pounds pressure. The contract specification requires that these pressers will take 98 per cent moisture sludge and reduce it to 80 per cent, with a guaranteed output of 54,000 pounds of 80 per cent sludge per day. Each pressing requires about three hours.

The presses when cleaned drop the sludge into a chute to storage bin, where a conveyor picks it up and takes it to the drier. Conveyor trouble was the cause of the idleness of the plant at the time of inspection. The original conveyor installed was of the drag type. It was found, however, that the sludge stuck to the drags and returned to the sludge pit, instead of dropping into the drier. A screw conveyor to replace the one now in place had been ordered and was expected at any time.

The drier is a type A, direct-indirect Buckeye, 60 inches in diameter and 40 feet long, driven by a 25-horsepower motor. Heat is furnished by an oil-burning furnace. Gases are passed through a condensing chamber which outlets into a high stack. It was stated that very little odor was produced.

The installation contract requires that the drier handle 54,000 pounds of 80 per cent sludge per day, reducing it to a 10 per cent basis with a consumption of 1 pound of fuel, containing 13,500 B. t. u. per 10 pounds of water evaporated.

From the drier the sludge goes to an 8-inch mesh screen, the screenings being carried into the storage bin, and the tailings to a grinder and thence to the storage bin. All transfer of sludge is handled by conveyors.

Laboratory.—The laboratory is housed in a frame building. It is adequate in size and equipment for necessary work.

B. SOUTH SIDE PLANT.

The bulk of the sewage treated at the south side plant is pumped at the south side pumping station. Here it is passed through a screen with 1-inch clear openings and lifted by two 12-inch No. 12 S., Gould centrifugal pumps to a 36-inch gravity line to the plant.

The south side plant is, in its main features and in most of its details, exactly the same as the north side plant, already described, the difference being that the south side plant is a two-unit plant, or half the size of the north side plant.

To avoid repetition, descriptions will be made by reference to the north side plant, only points of difference being noted.

Plant inlet.—See north side plant, except two instead of four 2½-foot channels to tanks, and by-pass is 30-inch.

Aeration tanks.—Two units the same in every respect and dimension as described for north side plant.

Air distribution system.—See north side plant.

Tanks.—These tanks are slightly different from the corresponding ones at the north side plant. The end and side slope start higher up and hence are steeper. The end walls are vertical for only 2 feet from the top, and the side walls 12 feet 10 inches, instead of 9 feet 7 inches, and 17 feet 3 inches, respectively, at the north side plant, giving slopes greater than 2½ to 1, instead of less than about 1¾ to 1.

Other dimensions, air and sludge lines, are the same at both plants. The south side plant, however, does not have the extra siphon outlets in addition to the weirs.

Reaeration tanks.—These are identical with those at the north side plant.

Power house.—In principle and general design this installation is the same as at the north side plant, though smaller to correspond to the size of the plant.

The power house itself is 36 by 24 feet and the air screening chamber is 16 by 16 feet with 4 panels. The panels are covered with muslin as against duck and canton flannel at the north side. The air intake to the blowers consists of one 16-inch header pipe to which are connected two No. 10 Sturtevant blowers driven by 150-horsepower General Electric motors, one variable and the other constant speed. These discharge into a 16-inch header which divides into two 12-inch lines for the tanks.

The sludge pump is the same as at the north side.

Because of the location of the plant it was necessary to provide a water supply. This is from a well pumped by a small motor-driven triplex pump.

Sludge disposal.—All sludge for the two years of operation has been pumped to a lagoon about 300 by 100 by 10 feet deep. This was about half full at time of inspection, and was counted upon for two years more service. There is no drying plant, but it is possible that sludge may be taken from this plant to the drier at the north side plant if it is found that the commercial value of the dried sludge is sufficient to warrant the transportation expense.

Laboratory.—There is a combination tool house and administration building but no laboratory at this plant, that at the north side plant serving both installations.

VIII. LEXINGTON, KY.

Sewage is received at the treatment plant in 30-inch concrete sewer. This discharges into the entrance channel in which is located the screen.

Screen.—This is a bar screen made of ⅜-inch bars spaced 2 inches center to center, and inclined at an angle of 30° with the horizontal. In plan it is 3 feet wide by 8 feet long. Screenings are raked up by hand onto a concrete platform from which they are removed by a wheelbarrow and spread over land nearby.

Grit chambers.—The sewage next enters grit chambers of which there are three, all 3 feet wide, but two are 26 feet 6 inches, while the third is 30 feet 9 inches long. Their effective depth is 4 feet 9 inches. Below this depth there is a channel, 12 inches deep at the inlet increased to 15 inches deep at the outlet in which is laid a 6-inch vitrified drain tile and the channel filled with one-eighth to three-fourth inch graded broken stone. These tile are extended by 4-inch cast-iron pipes to a 4-inch vertical Morris centrifugal pump, shaft connected to a 2-horsepower General Electric Co. motor. The pump and motor are located in the laboratory and administration building, and are used to pump out the grit chambers before cleaning.

Inverted siphon.—This siphon carries the sewage from the grit chambers under the Louisville & Nashville Railroad tracks to the influent channel of the Imhoff tanks. The siphon entrance chamber is 12 feet 6 inches long with an inlet width of 3 feet, which increases or flares to 8 feet within the first 5 feet, giving an 8 foot width for the remaining 7 feet 6 inches. There are two outlets or siphon pipes. The first is 24 inches, reducing to 18, and controlled by a 24-inch circular sluice gate. The second is an 18-inch pipe controlled by an 18-inch special Pacific flush tank siphon, the outlet arm of which is in the form of a T, one opening extending up above the discharge point of the siphon. The 24-inch straight opening is used regularly. When the flow becomes too great to be entirely taken care of by this pipe the siphon operates to take the excess, and the riser from the outlet arm of the siphon constitutes an overflow in case the siphon fails to function properly. The two 18-inch pipes pass under the railroad tracks and discharge through risers into an elevated tank inlet conduit.

Imhoff tank inlet conduit.—The conduit from the siphon to the Imhoff tanks is 410 feet long, 3 feet wide by 4 feet deep. At one point an angle of 68½° is turned on the arc. For the greater part of the way this conduit is elevated 5 to 6 feet above the ground, though it is planned eventually to fill under it. The installation is complete to serve 8 tanks but only the four farthest from the siphon have been built. The others are to be added as needed.

Imhoff tanks.—The four Imhoff tanks are of the single chamber, reversible, horizontal flow type. They are 68 feet long by 33 feet wide and of a total depth of 28 feet 8 inches. Sewage enters and leaves over two 12-foot weirs, the crest of which are 2 feet below the top of the tank. There are two gas vents, one over each of two hoppers, 6 feet wide by 13 feet long.

The flow chamber has a total depth of 14 feet below the flow line to the apex of the slot. Of this, 5 feet 10 inches is vertical wall above the sloping baffles forming the bottom. These have a slope of 1½ to 1. The slots are formed by sloping in all four walls of the tank and sloping out the four walls of each gas vent. This method of construction gives eight distinct slots, four longitudinal with the tanks formed by the four side walls of the two gas vents with the two side walls of the tank; and four across the tank at right angles to the flow, two of which are formed by two end walls of the tank with the two outside end walls of the two gas vents and two formed by the two inside end walls of the two gas vents with a vertical partition wall between the two hoppers terminating in a wedge. In all slots, the horizontal opening is 9 inches and trap overlaps 10½ inches.

Scumboards are located 18 inches from the inlet and outlet. In addition there are two baffles 21 feet 6 inches from the inlet and outlet. Both the baffle and scumboards extend from the top of the tank down about 3 feet below the surface of the sewage. They consist of 2-inch cypress boards 10 inches wide, slipped in grooves in the walls of the tank.

Below the slots the sludge or digestion chamber is 11 feet 1 inch deep, of which 4 feet 6 inches are in the hopper bottoms which are 27 by 20 feet wide at the top, sloping to 18 by 18 inches at the bottom. The slope of the bottoms, transverse and longitudinal are, therefore, about 2 to 1 and 3 to 1, respectively.

The settling capacity, exclusive of the gas vents, from the flow line to the apexes of the slots is 20,600 cubic feet or 154,500 gallons.

Each hopper has an 8-inch cast-iron sludge outlet pipe which rises vertically from a point 12 inches above the bottom to the top of the tank, but at a point 4 feet 6 inches below the flow line is connected by a T to a horizontal 8-inch line which runs across the tank and terminates in a small sludge well between two adjacent tanks. From this a 16-inch sludge line goes to the sludge bed. Water lines have been installed around the top of the hoppers with a connection directly under the bottom of the outlet sludge pipe.

The sludge storage capacity below the overlap of the slot is 8,700 cubic feet.

Siphon chambers or dosing tanks.—There are two dosing tanks for the trickling filters, each serving two of the filter units. The tanks are divided into two sections emptied by a 24-inch, Pacific flush tank, alternating, twin, lock-controlled siphon. The siphons are located in chambers 28 feet long by 10 feet 7 inches wide with sloping bottoms so that the depth varies from 4 feet 4 inches to 12 feet 4 inches, the last 5 feet 6 inches being level at the 12 foot 4 inch depth.

The total capacity of each chamber, including the siphon bell, is 2,575 cubic feet; of this, 1,465 cubic feet or about 11,000 gallons is available and constitutes the dose discharged on the filter at each discharge.

Trickling filters.—The filters consist of four units of trickling filters of one-half acre each, arranged in two sets of two each. The filters are all 238 feet 6 inches long, but the two outside filters are 92 feet 6 inches wide, while the two inside filters lying adjacent to each other are 91 feet 3 inches wide.

The floors slope 6 inches in the width of the filters equivalent to a little over a 0.5 per cent grade. Six-inch half tile drains with open joints are laid on 10½-inch centers. These pass through the wall of the filters and discharge directly into two secondary sedimentation tanks located between and each serving two filters. The ends are open and can be easily flushed by a hose for which connections are available.

The filtering material consists of 3½ feet of native limestone surfaced with 2½ feet of Georgia granite. The specifications call for 2 to 2½ inch stone, but there is some smaller than 2 inches so that as the filters stand the size is 1 to 2½ inch. Around the open points of the half tiles of the underdrains larger stone were placed by hand. The use of the granite for the top 2½ feet was due to a serious doubt as to the wearing qualities of the native limestone. Due to transportation difficulties, however, it was impossible to secure quite enough granite and a small section of the filter was filled to the top with the native limestone. At the time of the survey, August, 1920, after three years of operation there appeared to be very little if any disintegration.

Sewage is discharged from the dosing tanks through a 30-inch pipe, which, at the filter, is divided into two 20-inch lines which are gradually reduced to 12-inch at the lower end of the filters. All lateral distributors are 6 inches, laid on 13-foot centers and supported by the filter stone about 6 inches below the surface. Into these are set circular Taylor nozzles on 15-foot centers staggered on alternate lines, thus giving a uniform spacing of 15 feet over the filter. The hydrostatic discharge head on the nozzle varies from a maximum of 9.75 to a minimum of 2 feet.

Secondary sedimentation tanks.—Each set of two filters discharges into a secondary or final sedimentation tank. These tanks are located between the filters they serve, and form the bottom of the uncovered central pipe gallery. They have a total length of 221 feet 4 inches and a total inside width of 12 feet. This width is divided into three sections: Two channels of 1 foot each into which the filters discharge, and the third, a central channel of 9 feet into which, at the inlet end, the two side channels discharge. The sewage is thus carried back through the 1-foot channels to the 9-foot channel, and then through the 9-foot channel the complete length of the tank. The bottoms of the side channels are flat, but that of the central channel consists of 16 hoppers, each 9 feet by 13 feet 10 inches in plan at the top and 18 inches by 13 inches at the bottom. Each hopper has a 4-inch valve-controlled sludge outlet connected to the 4-inch suction line of a 6-inch Morris vertical centrifugal pump, shaft connected to a 10-horsepower General Electric Co. motor. This pump discharges into the inlet channel of the Imhoff tanks. It is operated about every six weeks.

Final effluent channel.—From the secondary tanks the sewage flows over a weir into a 30-inch cast-iron effluent pipe, which discharges into Town Branch through a 36 by 36 inch open concrete conduit.

Sludge beds.—There are two sludge bed units, each 105 feet long by 83 feet wide. Each unit is divided longitudinally by three 9-inch partition walls into four beds, 105 feet long by 20 feet 3 inches wide. One bed of each unit is again subdivided by removable wooden partitions into five sections 21 feet by 20 feet 3 inches. The two units lie adjacent to each other with a sludge channel between them 12 inches wide, 18 inches deep, with semicircular bottom. A similar channel lies also on the end of each bed nearest the tanks. They are laid on a 2 per cent grade. Openings with slide gates or stop planks permit the sludge to be put on any desired bed. Below each opening on the bed there is a concrete splatter plate 5 feet long and 3 feet wide flaring to 7 feet. Tracks, 24-inch gauge, run down the center for the length of the bed and connect by turntables to a main track which runs up on a trestle over the sludge dump.

The bottom of each bed slopes 2 inches from both sides to the center, a distance of about 10 feet, where an 8-inch open-joint tile drain is laid in a channel. These empty into an 8-inch main drain which runs to the underdrainage system of the trickling filters. The depth of the material in the bed averages about 1 foot, and consists of a one-fourth-inch surface of sand, under this 2 inches of one-sixteenth to one-fourth inch stone, then 4 inches of one-fourth to three-fourths inch stone, and finally 5 to 6 inches of 1 to 2½ inch stone.

Laboratory and administration building.—Though not equipped for laboratory work, the plant has a brick building 40 by 26 feet overall, in which a room 24 by 26 feet has been set aside for a laboratory. The stationary fixtures, hood, benches, sinks, and worktables are already in place. The remainder of the building is taken up with a toilet, shower bath, the inlet chamber of the inverted siphon, already discussed, and the pumping equipment for draining the grit chambers.

Overflows and by-passes.—The plant is so arranged that any or every device can be cut out of service. Just preceding the bar screen there is an overflow leading around the screen and grit chambers to the inverted siphon chamber. This overflow is available for heavy storm flows and is a safeguard against clogged screens. In addition to this overflow there is a by-pass around the grit chambers for screened sewage to the inverted siphon chamber. At the outlet of the inverted siphon a valve-controlled blow-off makes possible the discharge of the sewage at this point direct to Town Branch through an 18-inch cast-iron pipe. After leaving the tanks there is, on the line to the dosing tanks and just before entering them, a 24-inch valve-controlled by-pass pipe which leads to a 36-inch drain. This drain was installed to intercept and carry underground to Town Branch a former surface run or brook. The filters can be cut out by opening a valve at the end of the main distributors, allowing them to discharge just ahead of the outlet weir of the secondary tank, or the filters can be operated alone without the secondary tanks by emptying the two narrow 1-foot channels into the final effluent conduit at a point just beyond the weir of the 9-foot channel into the final effluent conduit.

IX. Reading, Pa.

Sewage treatment at Reading is divided into three steps at three different places. The sewage is first screened and grit removed at a pumping station in the southwest corner of the city. From this point it is pumped over a mile south to a large septic tank, from which it flows over a half-mile to trickling filters and secondary sedimentation tanks on Fritz's Island, the effluent finally entering the Schuylkill River.

Screens and grit chambers.—Sewage is received at the pumping station in a 54-inch brick sewer from which 54-inch leaders are taken to the two screen chambers. These chambers are circular, 20 feet in diameter and 19 feet deep, with flat bottoms, the sewage entering with the invert of the sewer 8 feet above the bottom. One foot below the invert of the sewer is the screen, supported by an iron grid, consisting of cast-iron plates with half-inch holes on 2-inch centers, laid in sections to cover the entire diameter of the pit. The sewage entering these chambers submerges the screens, during periods of operation, to a depth of 3 to 8 feet, depending on the extent of clogging. The sewage passes through the screens to a pit 7 feet deep and from it to the suction of the pumps.

This suction is located about 18 inches above the bottom of the screen chambers, the depth below the suction being available for retaining grit. It is obvious, as has been demonstrated, that this grit storage space is quickly filled, and that the grit is then washed on to the pump as rapidly as it is deposited.

The screens are cleaned by hand. One screen is thrown out of operation and the sewage pumped down below the screen plate. The exposed plate is then cleaned with a flat-edged scraper, the screenings being collected into a pile and shoveled into a bucket which is lifted to the top of the well, dumped into steel carts, and pressed. The steel carts have perforated bottoms, solid sides, and open fronts. A wooden cover is placed over the screenings and pressed down by a jackscrew operated by a handwheel. The pressed screenings are burned in an incinerator. For the most part, there is a fixed schedule of cleaning from 8 a. m. to 9 p. m. During the night the screens are cleaned when needed.

In cleaning the grit chambers, sections of the screen are removed, and the deposits shoveled into a large container which is raised and lowered by a motor-driven windlass, mounted on an I-beam traveler. By this arrangement the container can be conveniently placed in the pit, and, when full, lifted and carried outside the building where it is dumped into a wagon.

Pumping equipment.—This consists of a R. D. Wood 12-inch, horizontal, centrifugal pump, 6 m. g. d. capacity, direct connected to a 100-horsepower Westinghouse motor; and a R. D. Wood 15-inch, horizontal, centrifugal pump, 8 m. g. d. capacity, direct connected to a 150-horsepower Westinghouse motor. These are controlled both by hand and by a Cutler-Hammer automatic float device. The two pumps are never operated together.

From the pumps, a force main, 6,600 feet long and 20 inches in diameter, except for a few hundred feet near the pumping station, leads to the septic tank. On this line, at the pumping station, the sewage passes through an integrating direct-recording Venturi meter.

Septic tank.—This tank is 253 feet long by 51 feet 8 inches wide by 17 feet 4 inches deep. All sides are vertical and the bottom is flat with, however, a slight slope to facilitate removing sludge. The tank as a whole stands above ground. The bottom is divided into five compartments by transverse baffle walls, 4 feet high. These compartments are connected by openings 1 foot wide cut at both ends of the baffle walls. Crossbeams 1 foot high divide each compartment into four bays or smaller sections. A 6-inch sludge outlet is provided for each of the five compartments.

There are no surface baffles, but an outlet scum board extending 3 to 4 inches below the surface of the sewage is provided. This scum board normally stands near the outlet, but it is movable, and is used to pull scum toward the inlet end of the tank where it is shoveled off into a chute to a large drying area. This is done about twice a week.

The 20-inch force main passes through the bottom of the tank at the inlet end and rises vertically for 11 feet where it discharges the sewage into a horizontal 14-inch riveted steel header, about 45½ feet long across the tank. Twelve 5-inch holes, on 3½-foot centers, are cut in the header 45° below the horizontal.

The outlet is over a timber weir extending across the entire width of the tank with its crest 1.15 feet below the top of the tank. The effluent enters a trough 2 feet deep the full width of the tank and discharges through a 24-inch vertical pipe to a 30-inch line to the filters.

An overflow weir, 32 feet 3 inches long, is provided in one side of the tank near the outlet end. Its crest is about 5½ inches above the crest of the outlet weir and about 8 inches below the top of the tank. The sewage passing over this weir spills onto an apron projecting 10 inches from the side of the tank and falls into a channel leading to Angelica Creek just above its entrance into the Schuylkill River.

It was stated that this weir overflows every Monday for about four hours and occasionally for about a half hour during the rest of the week.

The total volume of the tank is 226,000 cubic feet. With the flow line 1 foot below the top, the available volume is 213,000 cubic feet. Considering also the 4-foot depth below the bottom baffles as dead space for sludge storage, the available sewage capacity becomes 161,000 cubic feet or 1,200,000 gallons, and 52,000 cubic feet for sludge.

Trickling filters.—From the septic tank the sewage flows in a 30-inch pressure main under Angelica Creek and Mifflins Arm of the Schuylkill River to the filter beds on Fritz's Island. The pressure line discharges at the center of the bottom of a weir tank 10 feet in diameter by 12 feet deep. The bottom of the tank is about 10 feet above the ground and 10 feet below the surface of the sewage in the septic tank. Inside the tank three walls, chords of the circle of the tank, divide the tank into a central triangular entrance chamber and three outside segmental shaped outlet chambers. The dividing walls are solid to a height of 3 feet above the tank bottom, and grooves extend up another 4 feet, so that 2-inch planks can be set in them to obtain separation of the flow into the three outside chambers by merely adjusting the elevation of the top planks which serve as weirs.

The three outside chambers discharge through two 24-inch and one 30-inch vitrified pipe to the siphon tanks of the filters. The two chambers, with the 24-inch outlets, feed only one filter each, but the third, with the 30-inch outlet, feeds two filters.

While at the time of inspection there were 4 dosing tanks of two types, 1 controlled by butterfly valves operated by floats and 3 by siphons, only the siphon type is described here, as it was stated that the butterfly valve tank was unsatisfactory and would be replaced by a siphon tank of the same design as the other three before the summer was over.

The siphon tanks are hopper shaped with three sloping and one vertical side. One of the sloping sides overhangs the filter bed and has openings cut in it near the top so that any flooding will be onto the beds. The tanks are 7½ feet deep and have a capacity of about 12,000 gallons. Sewage enters through a 24-inch pipe in the bottom and leaves through a 24-inch siphon.

The four filter units were installed at different times between 1907 and 1915, and, though built on the same general lines, they differ in details of design. They are all 1 acre in area. The details can be most satisfactorily given by considering each filter separately.

Filter No. 1.—This filter was constructed in 1911, being the third one built at the plant. The floor is of concrete, sloping both ways toward one central drain. Laterals of 6-inch half-round tile on 11-inch centers run from this drain to the two sides of the filters. Around and over the laterals to a depth of about 6 inches are laid large pieces of slag averaging 6 inches in diameter. Above this is the layer of regular filtering media of open-hearth furnace slag 4½ feet deep. The filtering media was specified 1½ to 4 inches in diameter, but either the screening was carelessly done or the slag had disintegrated, as much material under 1½ inches was observed on inspection.

The distribution system from the 24-inch siphon consists of four main 12-inch terra-cotta feed lines encased in concrete. These four lines extend one-fourth, one-half, three-fourths, and the full length of the filters, supplying the first, second, third, and fourth quarter, respectively. All are controlled by separate valves. From the main feed lines, 6-inch terra-cotta laterals, encased in concrete, are run on the bottom of the filter at 14-foot centers. The risers, 4-inch cast-iron pipes, are spaced 13 feet 8 inches on the laterals. Iron plates are bolted to the tops of the risers, and the 218 nozzles, Reading type, are screwed into these plates. As the nozzles are staggered on alternate feed lines, the diagonal distance between nozzles is about 15 feet 4 inches as against 13 feet 8 inches between two nozzles on the same lateral. As the original design called for 6 feet of filtering material and only 4½ feet was placed, the risers project about a foot to 18 inches above the beds.

Filter No. 2.—This filter built in 1909 was the second one to be installed. The concrete floor slopes from a central gallery toward the two sides, dropping 9 inches in about 100 feet. On this floor, following the slope, are the lateral collecting drains consisting of 6-inch half tile laid with a 1-inch space between two adjacent lines and with joints staggered. These discharge into the two main drains, one on each side of the filter, each 2 feet deep with circular invert molded into the bottom of the filter. These drains have a slope of about 5 per cent. They discharge into a 24-inch pipe running across the lower end of the filter and emptying into the secondary sedimentation tank.

The main feed line is a 24-inch pipe running down the center of the filter under the gallery, which is about 4 feet wide by 6¼ feet high. The lateral distributors, 6-inch tile pipe, are taken off the main feed line at 12-foot 4-inch centers, each line being controlled by a 6-inch gate valve located in the filter gallery. The risers, 3-inch cast-iron pipe, are taken off the lateral distributors every 12½ feet by 6 by 6 by 3 inch vitrified tees, the connection being surrounded by a block of concrete. Risers on adjacent laterals are staggered. The top of the riser is flanged, and a cap into which the nozzles, Weand type, are screwed, is bolted to this flange. This filter has 254 nozzles spaced 12½ feet on the same lateral, but with a diagonal distance between nozzles on adjacent laterals of about 13 feet 7 inches.

The filtering material consists of local feldspar, of 6 feet 3 inches to 7 feet deep, at the center and sides, respectively, of specified 1 to 2½ inch size. As in the case of filter No. 1, it was observed that there was considerable material less than 1 inch. This stone breaks into flat pieces with parallel cleavage planes.

Filter No. 3.—This filter, constructed in 1915, was the last one built. It is the same design as filter No. 1, except for the filtering material which consists of 5 feet of 3-inch slag. This material was carefully screened and is all of a very uniform size.

Filter No. 4.—This filter, constructed in 1907, was the first one installed. The bottom of the bed, which is of concrete, slopes 1 foot from both ends of the bed to a central trough across the bed. This trough is 2 feet wide and 4 inches deep at the sides, sloping to 12 inches deep at the center. At right angles to this trough 6-inch half-tile laterals are run on 10-inch centers up the sloping bottom to the ends of the filter. Concrete slabs 36 inches square, supported by sills over the ends of the half-tile laterals, cover the central trough. Around and over the lateral drains are laid large pieces of slag 5 to 6 inches in diameter. The 30-inch effluent pipe runs from the center of the collecting trough under the filter floor to the secondary sedimentation tank.

The filtering material consists of specified 1½ to 4 inch slag 5 feet deep. Either the slag has disintegrated or the screening was poorly done, for there is considerable material less than 1½-inch size most of which is too small for a filter of this type.

The distribution system consists of a 30-inch tile-pipe feed line across 96 feet of the inlet end, but outside the bed. From one end a 30-inch tile pipe and from the other end a 28-inch square conduit extends to the center of the filter and connects with a 24-inch header across the entire width of the filter. This header is divided into four sections by valves on either side of the two influent lines, each section serving one-quarter of the filter. From the 24-inch header are taken 8-inch lateral distributors on 13-foot 9-inch centers. These are embedded in concrete. The 4-inch risers fit into tees on the 8-inch lines, and are set on 14-foot 2-inch centers. As the risers are staggered, there is a diagonal distance of about 15 feet 5 inches between risers on alternate lines. The 218 nozzles, Weand type, screw into plates bolted to the top of the risers. As the risers were built for a 6-foot depth of filtering material instead of the 5 feet actually placed, they project about a foot above the surface of the filter.

Secondary sedimentation tanks.—Each filter has a secondary sedimentation tank constructed at the same time as the filter. While similar in general plan, the details are sufficiently different to warrant individual description.

Tank for filters Nos. 1 and 3.—In plan this tank is about 96 by 100 feet, with the sides vertical. It is 3 feet deep at the inlet end, sloping to 4½ feet at the outlet end, where there is a sump to which sludge is pushed when cleaning the tank, and from which it is pumped by a small portable gasoline engine driven pump. There is provided a 6-inch drain valve to take off the supernatant liquor over the sludge before its removal.

Sewage enters through four 12-inch pipes from the 24-inch line from the filter. The discharge is over a weir into a concrete trough, from which a 24-inch pipe leads to the river. There are no baffles or scumboards. The available capacity is about 300,000 gallons.

Tank for filter No. 2.—This tank is approximately 110 by 95½ feet in plan and 3½ to 4 feet deep at the inlet end, sloping to 5 feet at the outlet. The side walls are on a 1 to 1 slope. Arrangements for cleaning are the same as described for the tank for filter No. 1.

Sewage enters through eight valved 12-inch pipes tapping the 24-inch effluent pipe from the filter which runs parallel with the inlet end of the tank. The outlet arrangement is the same as the tank for filter No. 1. There are no baffles or scumboards. The capacity is about 300,000 gallons.

Tank for filter No. 4.—This tank is the same as that for filter No. 2, except that the inlet consists of four openings from the effluent pipe of the filter.

Sludge beds.—There are no specially prepared sludge beds. The sludge and scum from the septic tank are run onto a large low-lying sandy area which is cleaned once a year. Several doses are given, one on top of the other, but as the area is fairly large it has been able to handle all sludge so far.

The sludge from the secondary sedimentation tanks is also applied to land near the tanks. This land was originally cleaned of vegetation, but at the time of inspection, July, 1920, it was entirely covered with a rank growth of weeds. Because of the amount of land available, however, it has been possible to handle all the sludge by this method, which might best be described as a cross between lagooning and bed drying.

Disinfection.—When work is being done on the tanks or filters or the treatment devices thrown out for any reason, and when the sewage flow exceeds the capacity of the pipe from the tank to the filters, the sewage is pumped direct to the canal at the pumping station. At such times calcium hypochlorite is applied to the sewage. The dosing apparatus stands in the open on the bank of the canal and consists of two 50-gallon barrels, one of which is free and the other connected by a feed line to the discharge pipe into the canal. Fifty pounds of the hypochlorite are mixed in the free barrel and dumped into the stationary one, from which it is fed through a small hand-controlled valve to the sewage at a nominal rate of 150 pounds of hypochlorite per million gallons, or about 4½ to 6 parts per million, but with no retention or contact period for the reaction. It is very doubtful whether this treatment, as used here, is of much value.

By-passes.—There are many points at which it is possible to by-pass sewage direct to the river. At the pumping station the sewage can be discharged direct to the river through the canal. It is possible to by-pass the septic tank entirely or to turn the effluent from the tank into the river, by-passing the filters. The filter effluent can in turn be carried around the secondary sedimentation tank. The overflow at the septic tank has already been mentioned.

Laboratory.—A small laboratory building is provided at the filter plant installation on Fritz's Island, but all analytical work is done in the board of health laboratory at the city hall to which the samples are taken, the chemist seldom visiting the plant itself.

X. Rochester, N. Y.

A. BRIGHTON PLANT.

Grit chamber.—Sewage is received at the plant through a 24-inch gravity line. This discharges into a small distributing chamber from which it can be diverted into any one of three parallel grit chambers by shutter gates opening in three directions. The middle chamber has a straight flow throughout, but the sewage enters the two side chambers perpendicular to their longitudinal axis. In every case, however, the sewage passes through a vertical shutter distributing baffle with adjustable openings into the grit chamber proper. The over-all outside dimensions of the three grit chambers with their inlet and outlet channels are 33 by 21 feet. The effective dimensions are, however, much smaller. For each chamber, neglecting the inlet and outlet channels and terminating at the foot of the screens (to be described later), the effective length is but little over 9 feet and the width 4 feet. The bottom is in the shape of a trapezoidal hopper, into which fits a 1-yard container which is removable by a chain falls on a traveling crane. Over this is a false bottom made of a longitudinal wooden grating of 2-inch bars with 1-inch clear openings. This is pivoted at the upstream end, the downstream end being adjustable vertically to vary the depth of the channel with the flow of the sewage.

Screen.—Near the outlet of the grit chambers the sewage passes under an adjustable scumboard and onto an inclined cast-iron bar screen, with clear openings of $\frac{11}{16}$-inch.

After the plant had been operating a short time it became evident that very little grit was being carried in suspension. One grit chamber was, therefore, remodeled to act merely as an inlet channel to the screen. The width was reduced and the velocity thus increased. The plant is at present operating without grit chambers, the unconverted chambers being held to take care of any unusual situation, when an excessive amount of grit is carried into the sewage through a break in the sewers, or at time of new construction work.

From the screens the flow is over a spillway into a common discharge chamber. There is also an emergency spillway around the screens into this chamber to prevent overflow in case the screens should become clogged. The outlet of the discharge chamber is a 16-inch cast-iron pipe with a flaring mouthpiece which leads to the Pelton water wheel in the operating house 69 feet below and a distance of about 500 feet.

In case the wheel should be stopped, the discharge chamber at its head would overflow into a brick manhole from which is run a 12-inch overflow pipe to the operating house, but around the Pelton wheels. In the operating house there is a 6-inch valve-controlled connection between the two pipes, so that the 16-inch pipe can be blown out through the 12-inch one.

Two 10-inch pipes, reducing to 6-inch, are taken off the 16-inch pressure line to the water wheels, only one of which has, however, been installed. The discharge from the water wheel enters the chamber which also receives the flow from the 12-inch overflow pipe, and from there is sent to the Imhoff tank. The gates are so arranged that the sewage can be sent into either end of the Imhoff tank or can by-pass it altogether. There is also an overflow weir from the discharge chambers of the Pelton wheel to the effluent channel from the Imhoff tank.

All valves and partitions of the inlet and outlet channels of the Imhoff tank are controlled from and contained under the floor of the power house.

Imhoff tank.—The Imhoff tank is a combination of the circular and rectangular types. The side walls 32 feet 6 inches long are parallel, but the two ends are semicircles with 15-foot radii. The over-all, inside dimensions of the tank are: Length, 62 feet 6 inches; width, 30 feet; maximum depth, 37 feet to the top of the sides and 40 feet to the top of the gas vents.

There is but one flow chamber, 24 feet wide, with an effective length of 60 feet and maximum depth of 19 feet. The flow line is 2 feet below the top of the tank. No curvature is made in the side walls of the flow chamber; they terminate in the curved ends of the tank and extend 3 feet above the top of the tank. They are vertical for 9 feet below the flow line. The bottom is of rather unusual design and construction. From the bottom of the vertical sides it has a 1 to 1½ slope toward the center for a horizontal distance of 3.2 feet. Here it makes, with a triangular beam, a slot with a 6-inch slant opening. The apex of this beam is 1.6 feet above and one-half foot inside the slot. The inside slope of this beam is extended at the same slope of 1 to 1½ to a 6-inch slant width slot formed with a central triangular beam. In this way the bottom has four slots. The advantages claimed for the design are:

(1) A maximum settling area with a maximum sludge digestion volume for a given width and depth.

(2) The bottom can be cast in reasonable size slabs of uniform size at a convenient place where the best possible finish can be put on them and, when cured, can be set in the tank.

Outside of an inlet and outlet scum board there are no baffles in the flow chamber. The scum boards are made of galvanized iron and extend down 3 feet. Attached to the bottom of these boards are extensions of one-fourth inch wire mesh for the purpose of catching particles carried down by the current below the solid portion.

The inlet and outlet weirs are 10 feet long. The total capacity of the flow chamber from the flow line to the apex of the lowest slot is 20,400 cubic feet, or 153,000 gallons.

Below the flow chamber the digestion chamber has a total depth of 16 feet of which 6 feet is in the hoppers. There are two hoppers separated by a baffle wall. Each hopper is 30 feet wide and 30 feet long at the top, one end being semicircular with a 15-foot radius to conform to the ends of the tank. The bottoms slope to a point on a 2½ to 1 slope. Each hopper has an 8-inch cast-iron outlet pipe which starts very close to the center of the hopper, centering 7 inches inside of the transverse center lines, and extends without bends to the side of the tank through which it is carried by a Y connection, the main pipe also passing straight through the tank wall to above the flow line for cleaning purposes. A 5-foot hydraulic head is available over the outlet.

Around and halfway up the hoppers is provided a 2-inch pipe perforated on the bottom which is available for use with both air and water for agitation of a sludge. A half-inch pipe connection is also provided for introducing both air and water into the outlet pipe. The total capacity of the sludge chamber from the bottom of the hoppers to the overlap of the lowest slot in the flow chambers is 18,025 cubic feet.

Dosing tanks.—From the Imhoff tank the sewage passes to the siphon chamber through the effluent channel under the operating house. The siphon chamber discharges into the dosing tanks alternately. For operating purposes the siphon chamber actually extends back and includes a section of the effluent channel. At the end of the effluent channel the sides flare out from an inside width of 4 feet, to an inside width of 27 feet in a length of 11½ feet. Within this triangular chamber are installed four 20-inch Miller siphons each rated to discharge 5,000 gallons per minute under a 2-foot head. Only two of these are in use at present, the other two being held for future filter installation.

These siphons operate in rotation, each discharging into a separate dosing tank for one filter unit. The dosing tanks are 6 feet wide, 18 feet long, and 5½ feet deep at the inlet, sloping to 10½ feet at the outlet, where the main feed line to the filter leaves the tank flush with the bottom. Both the siphon chambers and dosing tanks are covered by a concrete platform roof.

The effluent from the Imhoff tank collects in the siphon chamber, backing up in the tank effluent channel till the level at which the siphon acts is reached. The proper siphon then discharges into its dosing tank which at that time is empty. The flow continues until the siphon breaks after discharging the stored or backed up sewage, plus the flow from the Imhoff tank during the period of discharge. It is thus evident that the duration of and volume of any dose depend upon the rate of flow from the tank. In heavy flows, therefore, the doses applied to the filters not only occur more frequently but are of longer duration.

As the dosing tanks are empty at the moment of discharge of the siphon, the nozzles start operating under a minimum head. This quickly builds up as the flow through the siphon is in excess of that through the filter nozzles. The nozzle discharge increases while the siphon discharge decreases as the head over it is lowered. After the siphon breaks, the head on the tricklers gradually drops till the dosing tank is empty.

As will be discussed later, the surface of the filter is sloped away from the dosing tank to compensate for the loss of head in the distributing lines. The hydrostatic head on the filters runs from 0 to 7 feet and back to 0 during each dose.

As stated before in connection with the siphons the dosing tank installation is for four filter units, but only two of them have been installed at the present time.

Trickling filters.—The filters are of the trickling type. There are two units each 189 feet long and 115 feet wide, giving an area of a half acre each. The nozzles are of the Columbus type, but during the winter a spreader is used to give a flatter trajectory similar to the Worcester nozzle. These are spaced 14 feet 4 inches center to center staggered on parallel lines to give the proper diagonal distance of 14 feet 4 inches between nozzles on parallel lines. There are a total of 113 sprinklers on each unit, the outside ones being 7 feet 6 inches from the walls.

As stated before, to partially compensate for frictional losses in the distribution system, the surface is laid with a slope of 1 foot in 200 in both the longitudinal and transverse directions.

The distribution system for each filter consists of a 12-inch cast-iron main line located in the filter gallery which lies between the two filters. From this line fifteen 5-inch laterals are taken, each feeding 7 or 8 sprinklers set in 2-inch cast-iron risers. Each lateral is separately controlled by a valve in the filter gallery and has a quick-opening valve at its lower end whereby the line is flushed daily. The laterals are supported on piers 3 feet high.

The filter gallery proper is 8 feet wide and over 6 feet high, well lighted with a window over each lateral connection. Within this gallery at its lower end is located a Gould triplex pump, gear connected to a direct-current motor for pumping the effluent from the secondary sedimentation tanks around the plant for use where it can be substituted for water. In designing this gallery particular attention was given to arranging pipes so as to use standard fittings instead of specials.

The filtering material is dense limestone of a specified uniform 1-inch size, averaging 6 feet in depth. Care was taken to secure the size specified.

The underdrains are laid lengthwise with the bed, at right angles to the distributors. They consist of 6-inch tile laid on a 1 to 200 slope, and spaced 7 feet 2 inches apart, the bottom being sloped toward them. Each drain discharges direct into the secondary sedimentation tank. It is possible to turn a flushing stream of water or final plant effluent into the upper ends of the drains and the lower ends are accessible for rodding.

With the present sewage flow there is no need of operating the entire filter area continuously. In 1919, with an average flow of about 1.1 m. g. d., only 66 per cent of the nozzles were in service. It is customary to allow certain sections of the filter to lie idle each day, but to rotate these sections so that the entire filter is benefited by the available excess capacity.

Secondary sedimentation tanks.—Following the trickling filters and receiving the effluent direct from the individual underdrains are the two secondary sedimentation tanks, one for each filter. These tanks are 115 feet 4 inches by 30 feet, with a depth sloping from 2 feet to 4 feet. The inlet side of the tanks are adjacent to the filters and the outlet end is along the filter gallery. This places the outlet end adjacent to and at right angles to the inlet. The sewage from different drains from the filters thus have settling or flow distances varying from but a few feet to over 115 feet. The outlet is in the form of a weir extending across a 30-foot end of the tank. This weir is protected from scum, and, in the winter time, from ice by a curtain wall extending about 18 inches below the flow line. The available capacity of each tank is 75,000 gallons or about two hours with the filters operating at 2 m. g. d.

Six-inch valved pipes to the effluent channel enable the complete drawing off the sewage, after which the sludge can be flushed or pushed to a 2-foot sluice gate and discharged.

Sludge disposal.—Under the original plans a two-unit sludge bed was constructed adjacent to the Imhoff tank. Each unit is 30 feet by 56 feet. The bottom consists of 6 inches of puddled clay. Over this is laid 6 inches of three-fourth-inch broken stone, then 4 inches of sand and gravel under 1 inch, and finally the surface of 2 inches of screened sand.

The bed is drained by 2-inch tile on a 0.5 per cent grade toward the dividing wall where there is provided a 6-inch collector which discharges into the secondary sedimentation tanks.

With an area of 3,360 square feet and an assumed population, allowing for growth of 10,000, the design was based on about one-third square foot per capita.

In 1918 the use of the sludge beds was temporarily dispensed with and a 12-inch line laid from the tank to a hollow to the north of the plant, where sludge was lagooned. No objectionable condition has resulted from this procedure, the lagoon being well screened by trees from the plant or from any other territory likely to be affected.[3]

Final effluent pipe.—Sewage from the secondary sedimentation tanks are carried by a 12-inch pipe about 1,000 feet to a submerged outlet in the main channel of Irondequoit Creek three-fourths mile above the head of Irondequoit Bay, an arm of Lake Ontario. For most of this distance there is a second pipe laid parallel and 2 feet distant from the first. This is a provision for the future but serves as a spare in case of trouble in the first pipe.

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[3] Since survey was made the use of the prepared sludge beds has been resumed.

B. IRONDEQUOIT PLANT.

Sewage is received at the plant in a rectangular sewer 10 feet wide by 4½ to 5½ feet deep, the bottom being curved on a 13-foot radius.

Included in the sewerage system tributary to the plant are two sand catchers with coarse bar screens. During the years 1918 and 1919, an average of 100 cubic yards per year was removed from these.

The flow of sewage is measured through a Venturi meter about 800 feet from the inlet to the plant.

Screens.—At the treatment plant the sewage passes through one of two bar screens with 3-inch clear openings into the grit chambers, each screen serving three grit chambers.

Grit chambers.—These are arranged in two parallel batteries of three chambers each, all independently controlled by 36 by 60 inch sluice gates and all with separate outlet channels. While there are six chambers in the installation only the four inside ones are used, the two outside ones being held for future enlargement of the plant. With the excess capacity over present requirements of the four operating chambers and the two unused ones, there is capacity available to double the size of the plant.

Each chamber is 90 feet long, 10 feet wide, and 9 feet deep. A 2-foot-wide channel in the center of the bottom extends the entire length of the chamber, sloping both ways to a 16-inch drain at the middle. This channel contains an 8-inch tile drain overlaid by 1¼ to 1½ feet of sand and gravel, by which it was intended to drain the grit before removing it. The remainder of the bottoms of the chambers is vitrified brick.

For cleaning the chambers tracks have been laid between them for an "A" frame derrick. With this the drainage system, as described above, is not used now, cleaning being done with the chambers standing full of sewage.

The bottom of the grit chamber is about 2 feet 9 inches below the level of the outlet channel. It was stated that grit should not be removed till it was about 3 feet deep. Up to this point considerable sludge is deposited at the outlet and it is necessary to displace this with grit and to allow it to wash out before removing grit.

Fine screens.—The sewage from the grit chamber enters short channels 21 feet long, 5 feet wide, and 6 feet 3 inches deep, which discharge onto Riensch-Wurl screens. These screens are arranged in parallel, there being no connection between them, and each is served by a grit chamber which can not serve any other screen. There are four screens in place at the present time, two with one-sixteenth by 2 inch slots, one with one-eighth by 2 inch, and one with three-eighth by 2 inch. The screens are all 12 feet in diameter with a frustum of a cone at the center, and are inclined 30° from the horizontal. They are of the bascule type, suspended from steel bridges, with no submerged bearings. Each screen is driven by an independent motor.

The three-eighth and one-eighth inch screens were originally used as a preliminary treatment to Imhoff tank sedimentation during normal flow and the two one-sixteenth inch were used at times of storm flow and constituted the entire treatment of the excess storm flow at such times, the effluent by-passing the Imhoff tank and going direct to Lake Ontario. At the present time either set is now used ahead of the Imhoff tanks.

The screens are cleaned by brushes on revolving spider arms which rotate, carrying the brushes over the surface of the screen exposed above the sewage. The cone section is cleaned by brushes which deflect the screenings to the plate section of the screen, where they are picked up by the revolving brushes mentioned above.

The brushes carry the screenings to a belt conveyor which drops them into a hopper from which small cars carry them to the screenings dump.

The one-eighth and one-sixteenth inch screens which have been operating three years showed considerable evidence of wear, especially on the cone. Grooves are cut in the metal by the brushes rubbing over the surface. Undoubtedly some sand or grit is picked up and held on the screens and some becomes bedded in the brushes. It was estimated that in another three years, making six years in all, the plates would have to be renewed. A set of brushes was stated to last six months.

Connecting channels.—The effluent channels from the screens, 5 feet wide by 7 feet deep, unite to form the influent channel to the Imhoff tanks. Each effluent channel is controlled by a 60 by 60 inch sluice gate. There are two channels connected by gate-controlled openings. One feeds the Imhoff tanks already constructed, and the other is for a duplicate set of tanks to be constructed when conditions require them. The latter may also carry storm water excess by-passing the tanks.

These channels are 494 feet long, 7 feet wide at the inlet, reducing after each inlet to two tanks to a final width of 2 feet. The depth is 6 feet for the entire length and the bottom is flat.

From this main feed channel the laterals are run to the tanks. These are 2½ feet wide by 6 feet deep. They connect with the tank at one near corner and discharge into either a channel running across the near end of the tank from which the sewage is taken over a weir or into a channel extending the length of the tank to an inlet channel across the far end similar to the one across the near end. Whichever one is the inlet, the other one serves as the outlet or effluent channel. The flow into the channels from the main feed channel is controlled by float-operated sluice gates so that each tank gets its proper proportion of the flow. There are two effluent channels from the tanks, one at the center and the other at the corner, adjacent to the influent channel from the main feeder. These channels lead to the main effluent channel located beneath the lateral feed channels.

Flow is reversed by quick-acting sluice gates. By-passing may be done from the main influent to main effluent channels.

The main effluent channel is 10 feet 6 inches wide by 1½ feet deep at the inlet end and 4 feet deep at the outlet. It is divided into two sections, one 3 feet and the other 6 feet wide, by an overflow weir wall. The normal flow is taken by the 3-foot channel, but when its capacity is exceeded the surplus flows over the dividing wall into the 6-foot channel.

Imhoff tanks.—There are in all 10 tanks arranged in five units of 2 each, but each tank is entirely independent. Sewage enters the tanks over 23-foot weirs located at both ends of the tanks and serving either as inlet or outlet weirs depending on the direction of flow in the tanks.

The tanks themselves are 110 feet long 35 feet wide and 39 feet deep. The flow line is 5 to 6 feet below the top of the tank.

Each tank has two flow channels 10 feet wide and 16 feet deep. Of this depth, the sides are vertical for 10½ feet and then slope on a 1 to 1.4 slope for 5½ feet to the slot. As stated before, however, the crest of the weir is 5½ feet below the top of the tank, so that there is available for sewage a depth of only 10½ feet. The sludge slot is of the double type, formed by the two sloping sides with the sides of the triangular beam running longitudinal with the tank. The clear opening is 8 inches.

The total volume of each flow channel is 15,300 cubic feet, but, as the flow line is so low, the available capacity to the crest of the weirs is only 9,240 cubic feet, or 69,000 to 70,000 gallons. The working capacity depends upon the head on the weirs.

The digestion or sludge chamber of each tank is 35 feet wide and 21 feet deep; of this depth 8 feet is in the hoppers, of which there are three, each 35 feet square on the top, and 3 feet 9 inches by 3 feet on the bottom, the slope being 1 to 2. All the digestion chambers are connected by openings in the walls between the hoppers, which, except for this opening, are solid across the entire tank below and around the flow channels. The opening is 8 feet high by 35 feet wide at the top of the hopper where it extends across the tank, but its sides slope to an 18-foot width at the top. Each hopper has an 8-inch sludge pipe extending diagonally upward through the side wall and discharging into a channel between each of the two tanks of each unit. Around each hopper are two water lines of 1½-inch perforated pipe. These are located vertical distances of 1 and 6 feet from the bottom of the hopper. These are used regularly to agitate sludge and when removing it, and are considered essential.

Each tank has three gas vents, one on each side, running the full length of the tank 2½ feet wide, and the third, 3½ feet wide, down the center, but lacking 10 feet at each end.

There are two scum boards located about 12 feet from each end and extending down about 12 inches. Outside of these there are no baffles.

The sludge compartment has a total capacity below the overlap of the slots of 57,500 cubic feet.

The outlet to the tanks has already been described under "connecting channel."

Sludge treatment.—Each unit of two tanks is served by eight sludge beds 44 by 44 feet, four on each side of a concrete trough which connects with the sludge channel, already described with the Imhoff tanks, by a 24-inch cast-iron pipe, about 33 feet long. The pipe and trough are laid on a 2 per cent grade. Sludge is discharged onto the center of the bed through an 18-inch opening controlled by stop boards in the side of the trough. The sludge drops onto 4 by 4 foot concrete splash plates.

The material of the bed consists of 2 inches of fine sand, 3 inches of coarse sand, 8 inches of gravel, and 6 inches of broken stone. Drainage is provided by 3-inch tile toward which the bottom slopes from both directions. These tile are laid on 8-foot centers and lead to a central drain located in a depression between two beds.

This depression between the first and second and the third and fourth beds of each row is 7 feet deep, about 4 feet below the bottom of the beds, and 9 feet wide. In this is laid a narrow-gauge track for sludge cars. The bodies of the cars are picked off their frame by a gantry crane traveling on tracks on the retaining walls of the depression between the beds and placed on the bed, where they are filled by hand. The crane then replaces them on their frame and they are hauled to the sludge dump by small electric locomotives driven by storage batteries.

There are two sludge dumps, one back of the plant, the other a tipple at the front of the plant from which sludge is dumped direct from the cars into wagons or trucks of farmers, who use the sludge as a fertilizer, paying a small sum for it. They also haul from the dump, but it is not nearly as conveniently situated.

Power development.—The divided tank effluent channel, already described, discharges into two steel effluent pipes. The storm flow 6-foot channel outlets into a 5½-foot outfall pipe which extends 7,000 feet into Lake Ontario, terminating in a submerged timber crib in water 50 feet deep. The 3-foot wide channel carrying the normal flow discharges into a 4-foot steel pipe or penstock of the hydroelectric plant. This plant has two 75-kilowatt generators which can furnish power for the crane at the grit chamber, the screens, the crane for the sludge beds, lighting, charging the storage batteries of the electric locomotives, etc. Power is also available from a public supply and is used more or less. The tail race of the power plant enters the 5½-foot outfall pipe.

By-passes.—These have been described at points at which they occur in the plant. The flow after leaving the grit chamber, the screens, or the tanks, or both, can be by-passed.

Laboratory.—The laboratory facilities are exceptionally good, both as regards space and equipment. They are located on a mezzanine floor which extends over part of the greenhouse. The laboratory work for both the Brighton and Irondequoit plants is done here.

XI. San Marcos, Tex.

The sewage enters the treatment plant through a 12-inch cast-iron pipe. This material was used, as it was necessary to carry the outfall across the San Marcos River on a trestle.

After passing through a small box inlet chamber set in the 12-inch line, the sewage is discharged into a septic tank.

Septic tank.—This tank was originally constructed as a storage tank for disposal of sewage by broad irrigation, but, after the construction of the present activated sludge plant, it was utilized to remove very coarse material which was found to give trouble in the aeration tank and return sludge line.

The tank itself is circular, 40 feet in diameter and 10 feet deep with an available depth below the flow line of about 8 feet. This gives an available sewage capacity of 10,000 cubic feet, or 75,000 gallons. The tank is plain in every respect, with flat bottom and no baffles.

The sludge outlet is a 6-inch pipe connected to a 6-inch centrifugal pump, belt connected to a gasoline engine. It is but rarely used, however, sludge having been removed but once in the past three years.

The sewage outlet is a 12-inch pipe, around the opening of which is a box frame about 3 by 3 by 2 feet covered with one-fourth-inch mesh galvanized wire screen. As the outlet is located only about 15 feet, chord distance, from the inlet, the period of detention is probably very short, certainly much less than the size of the tank would indicate. It is sufficient, however, to remove rags and gross suspended solids, and thus relieve the activated sludge plant of considerable burden and prevents clogging of the return sludge pipe.

Aeration tank.—This tank is 39 feet long, 16 feet wide, and 10 feet deep from the top of the tank to the filtros plates at the bottom. The sewage enters through a 12-inch pipe located at one corner. Three 3-inch walls divide the 16-foot width into four channels, the two outside 3 feet 10½ inches and the two inside 3 feet 9 inches wide. Openings, 3 feet wide by 7 feet deep, are left in these walls at alternate opposite ends of the tank to connect the four channels in series, thus giving a total flow length of about 150 feet.

The walls of the channels are vertical for a depth of 7 feet, where they slope in to form hoppers. These hoppers, built on 3-foot centers, are 3 feet deep with top areas of 3 feet by 3 feet 10½ or 9 inches and bottom areas 12 by 12 inches.

The total capacity of the tank is 4,750 cubic feet and the available sewage capacity about 3,840 cubic feet or 28,800 gallons.

Air distribution.—Air comes from the blower in a 5-inch pipe. This is increased to 8 inches and runs as a header parallel with the length of the aeration tank, and about 3 feet from it. Every 3 feet, 2-inch wrought-iron distributing lines are taken off. These drop along the outside wall to the bottom where they enter the concrete bottom and run across the tank encased in concrete. At the center of each channel risers enter the bottom of each hopper and terminate in a small chamber below the filtros plates. These plates form the bottom of the hopper and are cemented in with sulphur. This arrangement gives 13 lines, each feeding 4 filtros plates or a totel of 52 plates. The 2-inch feed lines continue through the tank to the clear on the far side, where they enter a 2-inch collecting pipe which runs on about a 4 per cent grade into a manhole located close by and is closed by a 2-inch valve.

By this means it is possible to drain any water from these lines. To remove accumulations of water in the space below the filtros plates, a three-fourths-inch drain is laid across the tank under each row of plates, on about a 4 per cent grade, to the manhole already mentioned, where it is provided with a valve.

After the plant had been operating for some time several of the filtros plates became clogged. To provide aeration at these points a 2-inch line from the main 8-inch air header was laid on the top of the dividing wall between channels 1 and 2, and seven one-half-inch pipes run down from this to within one-half inch of the top of the clogged plates. The air at these points, therefore, does not pass through any plates, but is discharged downward against the top of them. The distribution, however, appears to be very satisfactory.[4]

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[4] Since the survey the clogged plates have been replaced.

For the sedimentation tank, described below, a three-fourths-inch line is run from the main 8-inch header into the tank about 18 feet down from the top and turned up into the sludge pipe. The end is increased to 3 inches to fit the 3-inch sludge pipe and a brass plate with one twenty-fifth-inch holes soldered over the top of the 3-inch bushing. The air is discharged through these holes into the 3-inch sludge line, the perforations breaking up the air and effecting smooth and regular action of the pump without violent splashing and irregular shooting of sludge from the outlet.

Air is provided by a No. 10 Connersville blower, 6 by 10, with a rated displacement of 760 cubic inches of free air per revolution. During the period of the tests the average speed was 564 revolutions, or 248 cubic feet of free air per minute. The blower is belt connected to a 7½ horsepower Westinghouse motor and discharges to a tank, 24 inches in diameter and 24 inches high, the top of which is filled with excelsior to screen the air. From the tank the air passes through a 5-inch line to the 8-inch feeder already described.

Secondary sedimentation tank.—This tank is 20 feet long by 10 feet wide at the top and 25 feet deep. The end walls are vertical to a depth of about 2 feet where they slope in on an almost 2½ to 1 slope to the bottom which is 15 inches wide. The sides are vertical to a depth of 7 feet where they slope to a depth of 7 feet on a 2 to 1 slope to a 3-foot width. Below this they are vertical for 9½ feet where they again slope 18 inches to a 15-inch bottom.

The inlet is a 12-inch pipe in the corner adjacent to the end of the fourth channel of the aerating tank. The outlet consists of twelve 2-inch pipes turned up and capped by 2-inch tees bushed down to 1 inch. While there are twelve 2-inch outlet pipes available, only five are used. The other seven are capped and held in reserve should any of the five active ones clog. The openings are located to give a flow line about 2 feet below the top of the tank. All outlet pipes are collected in a header outside the tank and discharged into an open drain about 25 feet from the San Marcos River.

There is one baffle located about 3 feet from the inlet and extending down about 8 feet, leaving a 3-inch space between it and the sloping end wall of the tank. The outlet is protected by a scum board extending down 3 inches below the surface.

The sludge outlet is a 3-inch cast-iron pipe extending vertically down the tank, about 16 feet, to a Y. From the branch of this Y a 3-inch line goes to within about 9 inches of the bottom of the tank, while the straight end extends down about 3 feet and is closed by the plate on the end of the air line already described. Just above the top of the tank a 4-inch line is taken off at a T and run to the inlet of the aeration tank, discharging near the surface and directly over the first filtros plate. There is no sludge reaeration tank.

Sludge disposal.—Because of the presedimentation in the septic tank, the amount of sludge to dispose of is relatively small for an activated sludge plant. The sludge from the septic tank has to be removed only occasionally, because the storage available is very large for the sewage flow.

For the surplus activated sludge there are provided 2 sludge beds each 12 by 12 feet, made of cinders. Only one bed has underdrainage. In addition to these beds a small amount of sludge has been run into a small low area adjacent to the plant.

Overflows and by-passes.—At times of very heavy flows carrying considerable infiltration water, the small inlet box may overflow and the sewage spill over the ground to the creek. At this point it is also possible to by-pass the septic tank, sending the sewage direct to the aeration chamber. When the plant was first built the septic tank did not enter into the treatment.

Buildings.—The motor and blower are housed in a small frame building which was at one time also used as a laboratory to make a few simple tests. These have since been discontinued so that the building is now used only as a tool and machinery house.

XII. SHERMAN, TEX.

Sewage is received at the treatment plant in a 24-inch sewer on a 0.25 per cent grade which discharges into the screen chamber.

Screen chamber.—This chamber is 11 feet 9 inches long, 2 feet wide and 2 feet 8 inches deep. The screen is 6 feet 6 inches long, 2 feet wide, set at an angle of 18° with the horizontal. The openings are 1¼ inches clear between bars. Screenings are raked up by hand and deposited on a bar grating adjacent to the screen where they can drain. They are then thrown to the side of the chamber and later wheeled to a dump.

In one side of the screen chamber, an 18-inch weir with its crest 4 inches below the top of the screen provides an overflow for excessive flows or when the screens are clogged. The weir also has a sluice for by-passing all the sewage. The effluent enters a small chamber which discharges through a 15-inch sewer pipe to Town Branch, a tributary of the Red River.

Grit chamber.—The screen chamber discharges direct into the grit chambers. There are three of these in parallel with sluice gates at both ends. All are 57 feet long, and 2 feet 9 inches deep, but two are 18 inches wide, while the third is 2 feet. The bottoms are level but with a groove or channel 1 foot deep by 9 inches wide on top and 8 inches on the bottom. These hold a 4-inch tile drain laid in gravel and leading to a small discharge chamber, where they end with gate valves. The discharge chamber itself connects through an 8-inch vitrified pipe to a low-lying area selected for sludge beds, which, however, were never constructed. The grit is removed by hand about every three weeks.

Inlet channel.—The discharge from all three grit chambers enters a short chamber 8 feet long, 7 feet 2 inches wide, by 2 feet deep at the inlet and 4 feet 6 inches wide by 3 feet 6 inches deep at the outlet. This chamber empties into two channels 1 foot 10-¾ inches wide by 3 feet 6 inches deep which lead to the aeration tanks.

Aeration tanks.—At the present time only one of the two aeration tanks is complete. The other still lacks the filtros plates and air-distribution pipes. With this exception, they are duplicate units. However, as this one is not available, the plant is considered as having but the one unit.

The aeration tank is 24 feet 4½ inches wide, divided into three sections by two baffles starting from alternate opposite ends of the tank and stopping to allow an 8-foot opening between adjacent sections. They are thus arranged in series, giving a total flow length of about 200 feet, the total length of the tank being 75 feet. The total depth of the tank is 12 feet. The bottom consists of V shaped ridges on 5-foot centers across the tank separated by 1 foot 2 inch channels in which the filtros plates are set. A 6-inch channel cutting the ridges runs the length of the tanks through the center of each section to provide complete drainage to the top of the filtros plates, the channels being connected with the settling tank through a valve-controlled 8-inch pipe from the central aeration section. Sewage enters the tank direct from the inlet channel at one corner and leaves through an opening 3 feet wide at the corner diagonally opposite.

The total capacity of the tank is 19,775 cubic feet. With a water line 2 feet below the top, the available capacity is 16,656 cubic feet or 116,000 gallons.

Air distribution.—The main air line to the tanks is 12 inches. This divides into two 8-inch headers which reduce to 6 inches after supply lines have been taken off for two aeration tanks. The supply lines to the individual aeration channels run lengthwise with the tank over the center of each channel. The supply pipes to the first two channels start at 4 inches but are reduced at several points to a final 2½ inches. Over the third channel the pipe is larger, starting with 5 inches and reducing to 3 at the end of the tank, but it is continued at that size to the center of the sedimentation tank, where it reduces to 1 inch at a needle valve and drops down 12 feet below the top of the tank to the side branch of a Y on the sludge line. From the supply lines over the aeration tank, 2-inch galvanized iron pipes are dropped to the bottom of the tank, where they screw into cast-iron holders in which the filtros plates are set. These holders are 7 feet 5½ inches long by 13½ inches wide and hold five 12 by 12 inch filtros plates. There is an air space of a little less than an inch between the bottom of the holder and the filtros plates extending the entire length of the holder.

The main feeder line, from which the supply lines to the aeration tank are taken, is continued on top of and along the wall between the aeration tank and the reaeration tank. At several points it is reduced from 4 inches to 2 inches. From this line and at 10-foot centers 2-inch lines lead across the reaeration tank, and from these three pipes dropped to filtros plate holders, a pipe to each section in the tank. (See description of reaeration tank.) The holders in this tank are similar in design to those in the aeration tank, but are 5 feet 4½ inches long by 13½ inches wide and hold only four plates.

All drop pipes to filtros plates are independent, each having its own control valve.

Sedimentation tank.—As with the aeration tank two units have been constructed but only one is available for use.

This tank is 28 feet 4½ inches long 21 feet 10½ inches wide and 31 feet 4 inches deep. The two side walls are vertical for 15 feet 3 inches where they slope on about a 1.7 to 1 slope to the bottom which is 3 feet square. The end walls run on the same slope from the bottom, but as the tank is longer than it is wide, the slope extends up to within about 9 feet 9 inches of the top of the tank.

The inlet to the tank is an opening 3 feet wide cut in the common wall between the aeration tank and the sedimentation tank. This opening is 3½ feet deep, 1½ feet below the flow line of the tank and is located in one corner of the tank. The outlet is over a 3-foot weir.

In the inlet end, a baffle is hung 6 feet from the end of the tank, extending down 6½ feet from the top of the tank or 4½ feet below the normal water line which is estimated at 2 inches over the outlet weir. The outlet is protected by a scumboard placed 2 feet ahead of the weir.

The sludge outlet is a 6-inch pipe extending down within 9 inches of the bottom of the tank and terminating in a flared mouthpiece 12 inches in diameter. A horizontal 6-inch pipe from a T 2 feet below the top of the tank carries the sludge to the reaeration tank. Sludge is lifted by air which is introduced through a 1-inch pipe into the side branch of a Y set in the vertical 6-inch riser 12 feet below the top of the tank, or 10 feet below the flow line.

The effluent from the tank passing over the 3-foot weir enters an effluent channel 2 feet 1½ inches wide by 4 feet 4 inches deep, connecting with a 15-inch line which unites with the 15-inch overflow line from the grit chambers leading to Town Branch, a tributary of the Red River.

The total volume of the tank is 11,500 cubic feet. With the flow line 2 feet below the top the available volume is 10,000 cubic feet or 75,000 gallons.

Reaeration tank.—This is located alongside of the aeration tank. There is one for each aeration tank, but for reasons already stated only one unit is available.

The tank is 6 feet 7½ inches wide, divided into three channels, each 2 feet ½ inch wide, by 3-inch baffle walls similar to those described under the aeration tank, but with end openings of only 2 feet ½ inch. The two channels nearest the aeration tank are 75 feet long, but the third or outside channel extends beyond the aeration tank and overlaps the sedimentation tank by 10 feet, so that it is 85 feet long. Sludge is moved from the sedimentation tank through a 6-inch pipe discharging near the end of the long channel. The tank has a total depth of 12 feet, and of this depth 2 feet 3 inches is in the channeled bottoms, in which the filtros plates are set. There is only one row of plates in each channel, the holders being laid lengthwise with the tank. The outlet is a 2 foot ½ inch opening cut the full depth of the tank through the common wall between the reaeration tank and the aeration tank.

From the bottom of the tank at the inlet end a 6-inch vitrified tile sludge pipe, controlled by a sluice gate is run to the 8-inch line from the grit chamber drains, which leads to the low land where it was planned to build the sludge beds. There is also an 8-inch valve-controlled connection from the bottom of the tank to the sedimentation tank which permits draining of this tank and with it the aeration tank to the filtros plates.

Sludge disposal.—It was planned to provide sludge beds in low areas near the Town Branch. These, however, have never been constructed, and sludge is mostly disposed of by discharging it into the Town Branch at times of high water.

Power plant.—The power plant is housed in a concrete building 26 by 22 feet. This contains a Connersville blower, belt connected to a 24-horsepower General Electric Co. motor, having a capacity of 2.1 cubic feet per revolution. This installation is used almost exclusively as a reserve unit since it allows oiled surfaces to come in contact with the air, and oil is carried to the filtros plates. The regular unit consists of a Gordon City Fan Co. water cooled rotary compressor, belt connected to a 25-horsepower General Electric motor.

Air is taken from within the building. A box frame about 6 by 12 by 6 feet is suspended from the ceiling and covered with one layer of cotton flannel. The suction of the blowers extend into this box. Air can enter the building through two roof ventilators which are covered with a brass screen. It is probable, however, that the doors and windows provide as much if not more air than the ventilators.

Air is pumped to a tank, just outside the building, 3 feet 6 inches in diameter and 9 feet high, which is kept under 5 pounds pressure. From this tank the main feeder is taken to the tanks.

Laboratory.—There are no laboratory facilities at the plant nor any owned or controlled by the city.

APPENDIX II.

QUESTIONNAIRE FORM FOR THE ENGINEERING SURVEY.

[Sheet 1.]

DATA RELATING TO THE SEWERAGE SYSTEMS AND THE DESIGN AND OPERATION OF SEWAGE TREATMENT PLANTS AT SOME OF THE LARGER CITIES OF THE UNITED STATES.

City .... Date .... Survey by ....

Sewerage system:

1. Total population of city .... Census of 19.. Estimated by ....
2. Population contributing to treatment plant ....
3. Sewer connections ....
4. Combined or separate ....
5. Gradients ....
6. Infiltration and leakage..
7. Storm overflows ....
8. Flushing by hose, direct water connection, flush tank, etc. ....
9. Sewers:

Shape.	Size.	Description.
	Inches.	
.... feet	4	....
.... feet	6	....
.... feet	8	....
.... feet	10	....
.... feet	12	....
.... feet	15	....
.... feet	18	....
.... feet	20	....
.... feet	24	....
.... feet	30	....
.... feet	36	....
.... feet	42	....
.... feet	48	....
.... feet	60	....

10. Miscellaneous and remarks..

[Sheet 2.]

City ....

Sewage pumping:

1. Location of pumping station ....
2. Type of pumps ....
3. Power equipment ....
4. Method of operation, continuous, etc. ....
5. Suction well:
   - (*a*) Size and dimensions ....
   - (*b*) Screens ....
6. Control apparatus..
7. Discharge head..
8. Apparatus for measuring flow..
9. Miscellaneous and remarks ....

[Sheet 3.]

City ....

Sewage data (at outfall to treatment plant):

1. Volume—
    - (*a*) Dry weather flow ....
    - (*b*) Variations ....
    - (*c*) Storm waters carried to treatment plant ....
    - (*d*) Industrial wastes:
        1. Character ....
        2. Treatment of source ....
    - (*e*) Water consumption ....
2. Composition—
    - (*a*) Fresh or stale ....
    - (*b*) Floating material ....
    - (*c*) Industrial wastes ....
    - (*d*) Color ....
    - (*e*) Odor ....

[Sheet 4.]

City ....

Sewage treatment plant:

Sewer outlet at treatment plant—

1. Size and shape ....
2. Measuring weirs and recording devices ....
3. Storm overflows ....
4. By-passes, type and when used ....
5. Coarse screens ....
6. Miscellaneous and remarks ....

[Sheet 5.]

City ....

Grit chambers:

1. Number ....
2. Design including dimensions ....
3. Velocity of flow and detention period ....
4. Method of cleaning ....
5. Disposal of grit ....
6. Volume deposited per million gallons ....
7. Composition of grit—
    - (*a*) Average per cent water ...., average sp. gr. ....
    - (*b*) Odor ....
    - (*c*) General character ....
8. Loss of head ....
9. Outlet channels to tanks ....
10. Miscellaneous and remarks ....

[Sheet 6.]

City..............................

Fine screens:

1. Location and purpose..............................
2. Number..............................
3. Dimensions and description—
    - (a) Type..............................
    - (b) Mesh..............................
    - (c) General..............................
4. Capacity .... gallons per ....
5. Head required to operate ....
6. Method of cleaning ....
7. Screenings, volume per million gallons, wet..............................
8. Method of drying screenings ....
9. Method of disposing of screenings ....
10. Odor from screenings ....
11. Composition of screenings ....
12. Loss of head through screens ....

[Sheet 7.]

City ....

Sedimentation tanks—Primary, Secondary, Sludge digestion:

A. All types except Imhoff—
    1. Number and type ....
    2. Shape ....
    3. Dimensions ....
    4. Type of inlet ....
    5. Hoppers, number, shape, dimensions, capacity ....
    6. Baffles, spacing, surface or bottom..............................
    7. Scum boards ....
    8. Sludge outlets—
        - (a) Number ....
        - (b) Size ....
        - (c) Water pipes in connection with..............................
    9. Sewage outlet, size and arrangement for ....
    10. Velocity of flow, detention period, maximum, minimum, average.....

[Sheet 8.]

City ....

Sedimentation tanks (continued)—Primary, Secondary, Sludge digestion:

B. Imhoff tanks—
    1. Number ....
    2. Description, shape, inlets, outlets, etc., ...
    3. Flow chamber—
        - (a) Dimensions, capacity ....
        - (b) Size and shape of gas vents..............................
        - (c) Slope of incline partitions ....
        - (d) Width of slot and description ....
        - (e) Velocity of flow, vertical or horizontal ....
        - (f) Detention period, computed and actual, maximum, minimum, average ....
        - (g) Baffles, spacing, surface or bottom ....
        - (h) Scum boards ....
    4. Loss of head through tank ....

[Sheet 9.]

City ....

Sedimentation tanks (continued)—Primary, Secondary, Sludge digestion:

- B. Imhoff tanks continued—
  - 5. Digestion chamber—
    - (*a*) Dimensions, capacity to slot ....
    - (*b*) Hoppers, number, shape, dimensions, slope of sides ....
    - (*c*) Sludge outlets—
      - 1. Number and size ....
      - 2. Water connections for cleaning ....
    - (*d*) Baffles ....
    - (*e*) Storage of sludge in tank—
      - 1. Period ....
      - 2. Basis of design, cubic feet per capita ....
  - 6. Special apparatus or equipment ....

[Sheet 10.]

City ....

Sedimentation tanks (continued)—Primary, Secondary, Sludge digestion:

- B. Imhoff tanks (continued)—
  - 7. Foaming—
    - (*a*) When did foaming begin?................................
    - (*b*) How long did it persist?................................
    - (*c*) Season of year most active?................................
    - (*d*) How stopped or controlled, apparatus or devices used?........
      ....
  - 8. Population for which tanks are designed ....
  - 9. Miscellaneous and remarks ....

[Sheet 11.]

City ....

Chemical precipitation:

- 1. Chemicals used ....
- 2. Method of application (dry or wet) ....
- 3. Apparatus for applying ....
- 4. Where applied ....
- 5. Amount applied ....
- 6. Miscellaneous and remarks ....

Disinfection:

- 1. Chemicals used ....
- 2. Description of apparatus used ....
- 3. Amount of chemicals used ....
- 4. Where applied ....
- 5. Applied continuously throughout the year ....
- 6. Reasons for disinfection ....

[Sheet 12.]

City ....

Sludge production:
1. Volume wet sludge in cubic yards per million gallons........................
2. Methods of measurement ....
3. Per cent water, average, ...; specific gravity average, ...
4. Physical characteristics—
    - (a) Color ....
    - (b) Consistency ....
    - (c) Odor, when freshly drawn and after drying ....
5. Sludge drying beds description ....
6. Time required to dry sludge on beds. Depth of sludge applied ....
7. Mechanical apparatus for drying sludge—
    - (a) Description of apparatus ....
    - (b) Capacity (cubic yards of wet sludge per 24 hours)....................
    - (c) Per cent moisture of dried cake ....
    - (d) Time required for each cycle of operation ....

[Sheet 13.]

City ....

8. Final disposal of sludge—
    - (a) In lagoons ....
    - (b) Discharged in water courses ....
    - (c) For filling ....
    - (d) For fertilizer (make note of crops raised) ....
    - (e) Revenues ....
    - (f) Head over sludge outlet ....
    - (g) Miscellaneous and remarks ....

[Sheet 14.]

City ....

Activated sludge:
1. Sewage aeration tanks:
    - (a) Number ....
    - (b) Description of tanks (dimensions, etc.) ....
    - (c) Description of air diffusing apparatus at bottom of tank ....
    - (d) Type of blower ....
    - (e) Volume of air per gallon of sewage ....
    - (f) Duration of treatment ....
    - (g) Continuous flow or fill and draw ....
    - (h) Per cent of activated sludge returned to tank ....
    - (i) Apparatus for screening air ....
    - (j) Loss of head ....

[Sheet 15.]

City ....

Activated sludge (cont'd):

Sludge aeration tanks:
- (a) Design of tank ....
- (b) Diffusion, apparatus for ....
- (c) Volume of air...
- (d) Time of aeration ....
- (e) Loss of head ....

3. Miscellaneous and remarks ....

[Sheet 16.]

City ....

Filters:

1. Type ....
2. Number ....
3. Area and depth each unit ....
4. Filtering medium, size and composition ....
5. Method of applying sewage:
    (*a*) Flooding ....
    (*b*) Nozzles ....
    (*c*) Rate of treatment ....
    (*d*) Net rate per 24 hours ....
    (*e*) Head on nozzles ....
    (*f*) Siphons ....
    (*g*) Automatic control devices ....
6. Pooling ....

[Sheet 17.]

City ....

Filters—(cont'd):

7. Underdrainage:
    (*a*) How constructed ....
    (*b*) Slope of concrete bottom ....
    (*c*) Arrangement for flushing ....
8. Washing or other methods of cleaning ....
9. Flies, worms, and other forms of life ....
10. Growth on beds and in underdrainage ....
11. Condition of filtering media ....
12. Odors from filters ....
13. Resting of beds ....
14. Cowls or similar devices ....
15. Loss of head in filters ....

[Sheet 18.]

City ....

Ultimate disposal of sewage:

1. Receiving body of water ....
2. Physical conditions near outlet ....
3. Dilution available, dry weather ....
4. Use of water below sewer outlet ....
5. Miscellaneous and remarks ....

[Sheet 19.]

City..............................

Cost data:

1. Original cost:
    - (*a*) Per million gallon sewage..............................
    - (*b*) Per thousand population..............................
    - (*c*) By devices..............................
2. Modifications cost..............................
3. Cost of operation and maintenance.
    - (*a*) Man in charge of plant, title and salary..............................
    - (*b*) Chemists or bacteriologists, salary..............................
    - (*c*) Clerks..............................
    - (*d*) Skilled mechanics, etc. salary..............................
    - (*e*) Laborers, number, salary..............................
    - (*f*) Total cost of maintenance per year..............................
    - (*g*) Interest and depreciation..............................
4. Miscellaneous and remarks..............................

[Sheet 20.]

City..............................

General information:

1. Deterioration of concrete due to—
    - (*a*) Frost..............................
    - (*b*) Some constituents of sewage..............................
2. Odors from plants as a whole.
    - (*a*) At the plant..............................
    - (*b*) Distance from plant noticeable..............................
    - (*c*) Seasonal..............................
3. Improvements in receiving body of water after installation of treatment plant..............................
4. Condition of grounds about the treatment plant..............................
5. Extent of farming carried on at the plant..............................

[Sheet 21.]

City..............................

General information—(cont'd).

6. What population was plant designed for..............................
7. Are sludge drying beds large enough..............................
8. Modification of sludge beds suggested..............................
9. Night soil dumped into sewers..............................
10. Miscellaneous observation about plant not included under headings.........
    ....

Appendix III.

METHODS OF ANALYSIS.

Methods of Analysis.

The methods used are described in detail only where they differ materially from the procedure recommended in the Standard Methods of the American Public Health Association for 1925.

1. *Alkalinity.*—As in Standard Methods using methyl orange and sulphuric acid.

2. *Chlorides.*—As in Standard Methods.

3. *Relative stability.*—As in Standard Methods. Incubators were not available at any place visited. The samples were, accordingly, stored in the dark at a temperature as close to 20° C. as it was possible to find.

4. *Nitrogen as nitrates.*—As in Standard Methods, using the reduction method. The results are reported without any correction for nitrites. For the preparation of Nessler reagent, see under ammonia nitrogen, below.

5. *Settleable solids by volume.*—As in Standard Methods (p. 30). Conical glass vessels of 1,000 c. c. capacity (Imhoff cones) were used for raw sewages and tank effluents. For activated sludge, however, straight-sided cylindrical vessels, such as 1,000 c. c. graduates, are preferred.

6. *Suspended matter.*—As in Standard Methods. In the absence of constant temperature apparatus, the Gooch crucibles were dried over a water bath with suitable precautions to avoid moisture from condensed steam. The difference between this method of drying and that of drying at 103° C. is inappreciable.

7. *Ammonia nitrogen.*—As in Standard Methods, using copper sulphate as a clarifying agent. Instead of short tubes, bottles holding about 125 c. c. were used.

During the survey it was noted that difficulty was experienced in the preparation of Nessler reagent. It is thought advisable to give the method for the preparation of the reagent in detail.

REAGENTS FOR THE PREPARATION OF 1 LITER OF NESSLER REAGENT.

(a) *Iodide solution.*—Dissolve 50 grams of potassium iodide or 45 grams of sodium iodide in 80 c. c. of distilled water.

(b) *Hydroxide solution.*—Prepare a 50 per cent solution of sodium or potassium hydroxide. This solution should be prepared ahead of time and allowed to settle for a few weeks before use. The clear supernatant is decanted or siphoned off. For 1 liter of Nessler reagent, 285 c. c. of 50 per cent sodium hydroxide or 400 c. c. of 50 per cent potassium hydroxide will be required.

(c) *Mercuric chloride solution.*—About 350 c. c. of saturated solution will be required.

PROCEDURE FOR THE PREPARATION OF NESSLER REAGENT.

Add the iodide solution to a bottle calibrated roughly at 1,000 c. c. and then add the saturated mercuric chloride solution in 25 to 50 c. c. portions, with constant shaking, until about 300 c. c. have been added. The reddish precipitate which first forms dissolves more and more slowly. It is of importance that the iodide solution be completely saturated but not very greatly oversaturated with the mercuric chloride. When about 300 c. c. of mercuric chloride have been added, the addition of the mercuric chloride is continued as if in a titration with a very slow end-point, adding 5 c. c. portions with vigorous shaking until the reddish coloration has disappeared. When the end-point appears to be near, the mercuric chloride solution is added in 1 c. c. portions until a precipitate is obtained which persists for one hour. An additional one half c. c. portion should then cause the color to persist overnight, and if it does not, another half c. c. portion is added. When the end-point has been reached, 400 c. c. of 50 per cent potassium hydroxide solution or 285 c. c. of 50 per cent sodium hydroxide is added and the whole made up to 1 liter.

If required for immediate use, the solution may be filtered through asbestos, using suction. For small amounts a Gooch crucible is quite satisfactory. It is best, however, to allow the solution to settle for several days. It should then take on a clear greenish color. The reagent thus prepared improves until the bulk of the precipitate has settled out, after which no improvement with age can be detected. For use, it is decanted or siphoned into a small bottle in order to avoid stirring up the sediment on the bottom of the large bottle.

It is the experience of the writers that the sodium and potassium salts may be used interchangeably, i. e., sodium or potassium hydroxide may be used with either sodium or potassium iodide. The procedure is to be followed somewhat closely, since Nessler reagent, which is not sensitive enough, can not be materially improved by the further addition of reagents once the hydroxide solution has been added.

8. *Ether-soluble matter (fats).*—As in Standard Methods. In most cases, however, only 200 c. c. of sewage was used.

9. *Oxygen consumed.*—The procedure followed was essentially that outlined in Standard Methods, with slight modifications to minimize errors due to the deterioration of the reagents and to obviate the necessity of adjusting the oxalate and permanganate solutions to exact or equal strengths.

METHOD FOLLOWED.

REAGENTS—(*a*) *Sulphuric acid.*—The concentrated acid, specific gravity 1.84 was used as described below without dilution or addition of permanganate to free the acid from oxidizable matter.

(*b*) *Oxalate solution.*—Potassium or sodium oxalate was used. Ammonium oxalate dissolves slowly and is not superior to the alkali oxalates in keeping qualities. The following amounts are dissolved and made up to one liter in order to obtain an N/80 solution.

0.888 grams of ammonium oxalate, $(NH_4)_2.C_2O_4.H_2O$.
0.838 grams of sodium oxalate, $Na_2C_2O_4$.
1.151 grams of potassium oxalate, $K_2C_2O_4.H_2O$.

(*c*) *N/80 potassium permanganate.*—A N/4 solution is first prepared by dissolving 7.900 grams of $KMnO_4$ in distilled water and making up to one liter. This solution is reasonably permanent and need not be protected in any special manner. It serves as a stock solution for the preparation of the weaker N/80 solution. The N/80 solution is prepared by diluting 50 c. c. of the N/4 solution to one liter. The strength of the N/80 solution will decrease by about 2 per cent in a week or ten days, after which time deterioration will be much more rapid; it should be made up fresh every week. It may be checked against freshly prepared oxalate solution as described in Standard Methods, 1920, page 22, or, more conveniently, and with sufficient accuracy for the purpose at hand, against the standard thiosulphate used for dissolved oxygen determinations.

PROCEDURE.—To a 500 c. c. Erlenmeyer flask add 100 c. c. of distilled water followed by 2 c. c. of sulphuric acid, specific gravity 1.84. Then in all cases add 10 c. c. of N/80 potassium permanganate and a quantity of sample such that about 5 c. c. of N/80 potassium permanganate will be required for the back titration after addition of oxalate as described below. The following trial amounts are suggested:

10 to 20 c. c. of raw sewage.
25 to 50 c. c. of filter effluents.

A blank is run, using the same amount of distilled water, concentrated acid and permanganate as was added to the sample.

The sample and the blank are digested for 30 minutes in an actively boiling water bath. If the amount of sample taken was too large, as indicated by complete loss of color, the determination is repeated. When the digestion is complete, 10 c. c. of the oxalate solution is added to the blank and to the sample, and titration with permanganate is begun as soon as decolorization takes place.

COMPUTATION.—The value found for the blank is deducted from that found for the sample and is a correction for oxidizable substances in the reagents and for any difference in the strength of the oxalate and permanganate solutions. Following the above procedure,

$$\text{p. p. m. of oxygen consumed} = 100\frac{A}{B}$$

where A=c. c. of N/80 $KMnO_4$ required for the back titration less blank, and

B=c. c. of sample digested.

If the permanganate solution is not exactly N/80, a correction can be applied to the result found. Since the same amount of oxalate is added to both the sample and the blank, its strength is not a factor.

10. *Dissolved oxygen.*—The reagents given in Standard Methods, 1920, were used, except that sulphuric acid was substituted for hydrochloric acid in dissolving the precipitated manganese hydroxides. In the preparation of the reagents the sodium salts were used. A detailed description of the method is given below.

The sodium thiosulphate solution was prepared from an N/10 solution preserved by the addition of ammonium carbonate and chloroform after making up to the mark. This solution was reasonably permanent; titrations over long periods of time indicate a rate of deterioration of less than 1 per cent in six months. The N/40 solution is prepared by diluting 250 c. c. of the N/40 solution to one liter. The keeping qualities of the N/40 solution are somewhat improved by the addition of 5 c. c. of chloroform *after* making up to the mark. It will deteriorate rather rapidly, however, and should be made up fresh every few weeks.

The strength of the N/40 sodium thiosulphate may be determined by titration with potassium bichromate or permanganate. The use of potassium biniodate, the acid iodate, $KH(IO_3)_2$, is strongly recommended for this purpose, however. It can be obtained sufficiently pure for direct weighing without further purification, and its keeping qualities both in the dry state and in solution leave little to be desired. A N/10 solution is prepared by dissolving 3.250 grams in distilled water and making up to 1 liter. A N/40 solution is prepared by diluting 250 c. c. of the N/10 solution to 1 liter. The titration is exactly the same as when potassium permanganate or bichromate is used to titrate thiosulphate solutions. Since the use of potassium biniodate appears to be limited, the procedure will be given in detail.

STANDARDIZATION OF THIOSULPHATE SOLUTIONS WITH POTASSIUM BINIODATE.

Reagents.—(*a*) Standard potassium biniodate solution, also called potassium acid iodate, Kaliumbijodat, $KH(IO_3)_2$ or $KIO_3.HIO_3$: molecular weight 389.95. A N/10 solution contains 3.250 grams per liter according to the following reaction:

$$KH(IO_3)_2+10\ KI+11\ HCl=11KCl+6\ H_2O+(6\ I_2=12\ I)$$

$$N/10\ KH(IO_3)_2=\frac{389.95}{10\times12}=3.2496=3.250 \text{ grams per liter.}$$

A N/40 solution contains 0.8124 grams per liter. The N/40 solution is best prepared by diluting 250 c. c. of N/10 potassium biniodate to 1 liter. The solubility of potassium biniodate is 1.33 per cent at 15°. A saturated solution would be about

N/2.5. Solutions stronger than N/10 are not recommended. Moderate heat may be applied when a solution is being made up; the solution is, of course, allowed to cool before making up to the mark.

(*b*) Potassium or sodium iodide. The dry crystals may be conveniently used if free from iodates. With an iodide of doubtful purity it is best to use a freshly prepared 10 per cent solution (5 grams of NaI or KI in about 50 c. c. of distilled water).

(*c*) Dilute acid. H_2SO_4, 1:10, or HCl, 1:5, may be used. HCl should be free from Cl_2.

(*d*) Starch solution.

If acid and iodide are known to be pure:

(*a*) Dissolve a few crystals of KI or NaI, about 0.5 gram, in 50 c. c. of distilled water contained in a 200 c. c. beaker. Solution should be complete since acid added in next step may react with crystalline iodides.

(*b*) Add 2 c. c. of dilute acid; if no color develops, proceed as under "The titration" below.

If any color develops, the acid-iodide mixture contains impurities which must be taken into consideration. If in doubt as to color, or, in any event, with reagents of dubious quality, add a few c. c. of starch solution to confirm. If no color develops, the reagents are of suitable quality. Since the starch would interfere if added at this stage, a fresh acid-iodide solution is made up for the test. The reaction with iodates is as follows:

$$KIO_3+5\ KI+3\ H_2SO_4=3\ I_2+K_2SO_4+3\ H_2O$$

If iodide or acid contain impurities:

(*a*) Add 2 c. c. of dilute acid to 50 c. c. of distilled water contained in a 200 c. c. beaker. 0.2 c. c. of conc. H_2SO_4 may be added instead of the more dilute acid.

(*b*) Add 5 c. c. of 10 per cent iodide solution.

(*c*) Add 1 or 2 c. c. of starch solution.

(*d*) If a color develops, titrate to an end-point with the thiosulphate solution to be tested, noting the amount required. This amount is a correction to be deducted from the final reading.

(*e*) Prepare a fresh acid-iodide solution as in steps "*a*" and "*b*" under this heading, and proceed as under the following:

The titration.—(*a*) Add a little less than 40 c. c. of N/40 biniodate to a 200 c. c. Erlenmeyer flask. Do not wait for burette to drain completely. Less biniodate may, of course, be used, depending on the accuracy which is sought. The procedure as outlined should check within one-tenth of 1 per cent.

(*b*) Adjust and read the burette containing the thiosulphate to be standardized.

(*c*) Pour the acid-iodide solution prepared above *into* the 200 c. c. Erlenmeyer flask containing the measured amount of standard biniodate.

(*d*) Titrate at once with N/40 thiosulphate, avoiding agitation until the bulk of the thiosulphate has been added. The solution is rather concentrated with respect to iodine, and loss is to be guarded against.

(*e*) When a pale straw color is reached, add 1 or 2 c. c. of starch solution and titrate to an end-point.

(*f*) The end-point may be checked by adding enough biniodate to cause the color to return and again reaching an end-point with thiosulphate. If any great accuracy is desired, the sides of the Erlenmeyer flask may be rinsed down with distilled water. It is convenient to use exactly 40.00 c. c. of biniodate since in this case 0.10 c. c. equals one-fourth per cent. Burettes will drain by as much as 0.2 c. c.; hence about 3 minutes should be allowed before taking the final readings.

(*g*) If the iodide or acid contains impurities, the amount found above ("*d*" under "if iodide or acid contain impurities") is to be deducted from the indicated amount of thiosulphate required for the neutralization of the biniodate.

NOTES ON ABOVE PROCEDURE.

(*a*) Biniodate solutions are very stable. Under average conditions the N/10 solution will hold up for at least a year.

(*b*) N/40 $KMnO_4$ or N/40 $K_2Cr_2O_7$ may be substituted for N/40 $KH(IO_3)_2$. The procedure is exactly the same as outlined.

(*c*) N/10 sodium thiosulphate may be standardized as above, using 20 to 25 c. c. of N/10 biniodate, and twice as much KI and dilute acid, i.e. 10 c. c. of 10 per cent KI (1 gram) and 4 or 5 c. c. of 1:10 H_2SO_4 (or 0.5 c. c. of the conc. acid).

(*d*) The amount of iodide used is far in excess of the requirements for the reaction given. If less is used, however, the iodide will not dissolve and may escape by volatilization.

(*e*) Iodide solutions deteriorate rapidly. Chem. Abs., 9:2289, states that KI solutions rendered slightly alkaline with $Mg(OH)_2$ will keep clear in bottles, even in the light, without danger of decomposition.

(*f*) The amount of acid added may be doubled or halved without apparent effect. If too much acid is added, however, the starch will break down (erythrodextrine) forming a red color and giving a poor end-point. If too little is added, the reaction will not proceed as above. In a neutral solution the biniodate is only one-twelfth as strong.

$$6KIO_3.HIO_3+5KI=11KIO_3+6I+3H_2O$$

Hence one molecule of $KIO_3.HIO_3$ liberates only one atom of iodine instead of 12 as shown above.

(*g*) Potassium permanganate may be substituted for potassium biniodate in the above procedure, i. e., once the value of the thiosulphate solution has been determined, it may be used to standardize a permanganate solution.

(*h*) Potassium iodate may also be used to titrate hydroxide solutions, using phenolphthalein as an indicator. In this case, however, the reaction is:

$$KIO_3.HIO_3+KOH=2KIO_3+H_2O$$

i. e., the potassium biniodate has only one-twelfth the value that it possesses as an iodimetric standard. Otherwise stated, 12.00 c. c. of the N/10 solution prepared above (3.250 grams per liter) are equivalent to 1 c. c. of N/10 KOH (or NaOH). The hydroxide solution should be free from carbonates. This adaptation, however, possesses no particular advantage.

PROCEDURE FOR DISSOLVED OXYGEN TEST, USING THE PERMANGANATE MODIFICATION OF THE WINKLER METHOD.

The procedure followed was essentially that given in Standard Methods. It has been found, however, that the results are apt to be erratic unless the procedure is adhered to strictly. For this reason the method will be reproduced in somewhat detailed form. Particular importance is attached to the avoidance of an excess of oxalate solution, since with any great excess of this reagent low results are obtained. This effect is counterbalanced somewhat by the addition of an excess of acid just before the titration. For this reason sulphuric acid is used instead of hydrochloric acid.

In many cases it is not necessary to use the preliminary treatment with permanganate. This however, is best determined for each individual waste.

PRELIMINARY TREATMENT WITH PERMANGANATE.

(*a*) Add 0.7 c. c. of concentrated sulphuric acid, specific gravity 1.84, to the sample contained in a 300 c. c. bottle. It is important that the amount of acid called for should not be exceeded. The 0.7 c. c. portion, for that reason, is best added with a 2 c.c. pipette.

(*b*) Add 1 c. c. of N/5 $KMnO_4$, unless experience shows that a larger amount is consistently necessary for the particular sample being tested. The N/5 $KMnO_4$ need be but approximate.

(*c*) Shake well and allow to stand for 20 minutes.

(*d*) If the amount of $KMnO_4$ added as in "*b*" appears to be insufficient after the sample has stood for some time, add more N/5 $KMnO_4$ in 0.5 c. c. portions with shaking and suitable delay between additions. The attempt should be made to keep the amount of permanganate added down to a minimum.

(*e*) After the sample has stood for 20 minutes in the presence of an excess of permanganate, remove the stoppers and add 0.5 c. c. of 2 per cent potassium oxalate ($K_2C_2O_4.H_2O$). This solution deteriorates rapidly and should be made up fresh at least every week. Shaking is necessary for the proper distribution of the oxalate.

(*f*) An excess of oxalate is to be avoided for two reasons:

1. The time of decolorization is lengthened when too large an excess of oxalate is added.
2. An excess of oxalate lowers the apparent oxygen content of the sample.

(*g*) If after standing for 4 minutes the color of the permanganate still persists, an additional 0.5 c. c. of 2 per cent oxalate is added. Unless the amount of N/5 $KMnO_4$ added has been excessive, this second portion should induce complete decolorization.

(*h*) If a decided excess of oxalate is added, the color due to the permanganate will be quite unchanged until decolorization is almost ready to take place; the sample will assume a brownish color if the amount of oxalate added was insufficient.

(*i*) When the permanganate is fully decolorized, add the Winkler reagents in the following order. Do not add less than the indicated amounts.

1 c. c. of manganous sulphate solution and 3 c. c. of alkaline iodide solution. The manganous sulphate solution contains 480 grams of $MnSO_4.4H_2O$ or 400 grams of $MnSO_4.2H_2O$ per liter. The alkaline iodide solution contains 700 grams of KOH (or 500 grams of NaOH) and 150 grams of KI (or 135 grams of NaI) per liter.

If the preliminary treatment with permanganate as outlined above has not been used, the test is started with the addition of 2 c. c. each of the manganous sulphate and alkaline-iodide solutions. The subsequent procedure is the same in either case.

(*j*) Shake well to neutralize the acid as fast as possible and to distribute the precipitate uniformly throughout the bottle. The precipitate is then allowed to settle until contained in the lower half of the bottle and the bottle again shaken. If a clear supernatant is not obtained, the shaking may be repeated.

(*k*) Add 2 c. c. of concentrated sulphuric acid, specific gravity 1.84. The acid is allowed to flow down the neck of the bottle.

(*l*) Shake well, since the liberated iodine diffuses but slowly. It should be uniformly distributed throughout the bottle before any is withdrawn for titration.

(*m*) If the preliminary treatment has been used, pour out 101.9 c. c. of sample into a flask calibrated to hold that amount. The correction of 1.9 c. c. is based on the assumption that the reagents are entirely devoid of oxygen;

0.7 c. c. of H_2SO_4
1.0 c. c. of N/5 $KMnO_4$
3.0 c. c. of alkaline iodide solution
1.0 c. c. of manganous sulphate solution

5.7 c. c. added to a 300 c. c. bottle requires a correction of 1.9.

This assumption is only partly correct, since some of the reagents undoubtedly contained some oxygen. No correction is made for the addition of oxalate solution, since this is presumably saturated with oxygen. No correction need be made for the acid added just before the titration, since no dilution of the sample is involved. The correction for the reagents added somewhat balances the slightly lower results obtained due to the use of oxalate.

If the preliminary treatment has been omitted, 101.3 c. c. of sample are measured out.

If desired, 200 c. c. portions of the sample may be titrated or the entire bottle may be taken. It is not believed, however, that any greater accuracy will result.

(*n*) Pour out the measured amount of sample into a 200 c. c. Erlenmeyer flask and titrate with N/40 thiosulphate until the amount of iodine remaining is about equivalent to 0.5 c. c. of N/40 thiosulphate. This is a pale straw color.

(*o*) Add 1 or 2 c. c. of freshly prepared starch solution and titrate to the disappearance of the blue color. The end-point should be obtained with 0.05 c. c. of N/40 thiosulphate without difficulty.

(*p*) Where several samples are being run at the same time, four or five flasks may be poured out at once if the titrations are made rapidly and promptly. The loss of iodine by diffusion into the air is appreciable if the oxygen content exceeds, say, 7 parts per million, and the titration is unduly delayed.

(*q*) If the amount titrated is equivalent to 100 c. c. of the original sample, the dissolved oxygen content in parts per million is twice the number of cubic centimeters of N/40 thiosulphate used.

11. *Biochemical oxygen demand.*—The excess oxygen method was used in all the determinations made. Since this method is not described in Standard Methods and is not in general use in this country, it will be given somewhat in detail. The method has been used extensively by the Public Health Service with good results. It has advantages of simulating natural conditions more closely than any other and the values derived are of fundamental importance. With suitable working arrangements the tests can be carried out rapidly and conveniently.

DEFINITIONS.

The biochemical oxygen demand of a polluted water, a sewage or an industrial waste is defined as the milligrams of oxygen per liter required for the stabilization of its organic matter by aerobic bacterial action.

The initial oxygen demand is defined as the milligrams of oxygen per liter that may be taken up on dilution with aerated water by a sample devoid of oxygen even if the sample is sterile. This purely chemical part of the oxygen requirement may be due to the presence of easily oxidizable sulphides, ferrous salts, etc., and is generally satisfied during the first few hours of incubation. It represents the oxygen which would be required within a few hours after the discharge of a waste into a stream.

RATIONALE OF THE METHOD.

The sample is incubated at 20° C. for a definite period of time. The dissolved oxygen content of the sample is determined before and after incubation, and the amount of oxygen used up is taken as a measure of the oxygen demand of the sample for the period of incubation used. If there is an appreciable initial oxygen demand it is determined and deducted from the total value to obtain the biochemical oxygen demand. If the sample is sterile it must be seeded with sewage bacteria. If it contains an insufficient amount of dissolved oxygen it must be diluted with water containing dissolved oxygen, in which case a correction must be made for the oxygen demand of the diluting water used.

APPARATUS, GLASSWARE.

Carboys.—Twenty liter capacity, to store tap water for dilution purposes. Distilled water may be used without storage, if of suitable quality.

Incubation bottles.—Preferably of 250 to 300 c. c. capacity and provided with ground-glass stoppers.

Devices to provide for volume changes during incubation or for entrapping liberated oxygen.—If it is desired to use devices of this character, it will be found convenient to use "open tubes" as devised by H. W. Streeter at the Baltimore sewage laboratory and later improved by him in connection with the Ohio River Investigation by the United States Public Health Service. These tubes are 6 inches long, and should be of thick glass of at least one-fourth inch inside diameter, with the edges smoothed in a flame. They are fitted at the center with a piece of heavy rubber tubing one inch long, slipping snugly over the tube, and of such thickness as to completely close the neck of the bottle. This device acts practically as a one-hole rubber stopper and a piece of glass tubing. To insert, place the moistened tube in the bottle until the rubber touches the liquid, then, holding the index finger over the open end of the tube, depress same into position. This device is not recommended as essential for 20° C. work.

Dilution flasks.—Two are required, one of 1,000 c. c. and one of 500 c. c. capacity.

Siphons.—Two siphons are necessary, one for filling the dilution flasks (see Fig. 1) and a smaller one for filling the bottles from the flasks. The siphons are easily made from glass and rubber tubing.

Incubator.—This should be capable of regulation within one degree of 20° C. Where incubators are not available, the samples should be stored in the dark as near to 20° C. as possible and a record made of the temperature.

REAGENTS.

As given for dissolved oxygen determination in Standard Methods of the American Public Health Association.

DILUTING WATER.

It is essential that the diluting water should have the following characteristics at the time of use.

(*a*) Its 10-day biochemical oxygen demand should be less than 0.6 parts per million.

(*b*) It should not be supersaturated with dissolved oxygen; i. e., its dissolved oxygen content should be less than 9.0 parts per million.

(*c*) The temperature of the diluting water should be approximately 20° C., if devices to provide for volume changes during incubation are not used.

Water fulfilling the above requirements can be easily obtained by storing water at about 20° C. until its oxygen demand is suitably reduced. For Cincinnati tap water, with a 10-day oxygen demand of about 1.3 parts per million, a storage period of 7 to 8 days is sufficient.

During the survey it was impracticable to use stored tap water for dilution purposes and accordingly distilled water was used. The results obtained indicate that distilled water can be used if desired. Apart from the added expenses involved, the use of stored tap water, however, is probably to be preferred, since distilled water generally contains appreciable amounts of free ammonia and nitrites and, being presumably sterile and devoid of mineral salts, is not strictly a blank.

PRELIMINARY DETERMINATIONS WITH INDUSTRIAL WASTES.

(*a*) If the sample is acid or possesses hydrate alkalinity, bacterial activity will be inhibited. Neutralize with $NaHCO_3$ or Na_2CO_3. If the diluting water has a high bicarbonate alkalinity, this may be sufficient to neutralize the acidity or hydrate alkalinity of the sample in the concentration incubated.

If the sample is acid or possesses hydrate alkalinity or has been boiled, it should be seeded with sewage bacteria before incubation.

(*b*) The dissolved oxygen content of the sample is an index of its biochemical oxygen demand. If no oxygen is present, it indicates that the sample is heavily polluted; samples which have been heated or contain reducing chemicals are exceptions. Dissolved oxygen may also be present if the pollution is but recent. If the oxygen content is high the sample may be incubated without dilution, e. g., river water and effluents of good quality for short periods of incubation. If the sample contains over 9.0 parts per million of dissolved oxygen, "open tubes," as described above, may be used to trap any oxygen which might be liberated or, preferably, the excess of oxygen is removed by applying suction to a bottle partly filled with the sample. An apparent supersaturation may be obtained if nitrites are present and the Rideal modification is not used.

CHOICE OF CONCENTRATIONS TO BE INCUBATED.

The concentration of waste incubated should be such that sizable depletions are obtained. If several concentrations are to be put up, they are made each 50 per cent of the next highest until the desired range has been compassed. The number of concentrations to be incubated will depend on the certainty with which the behavior of the sample is known and the duration of the incubation. For raw sewage, 5 and 2.5 per cent concentrations are suggested as trial amounts for 5-day periods of incubation. Final effluents of good quality may often be incubated without dilution.

METHODS OF PREPARING THE DILUTIONS.

(*a*) Suitable amounts of the sample may be added directly to bottles of known capacity. This, however, complicates the computations and may introduce a considerable sampling error if small amounts of samples are involved. The following procedure is recommended:

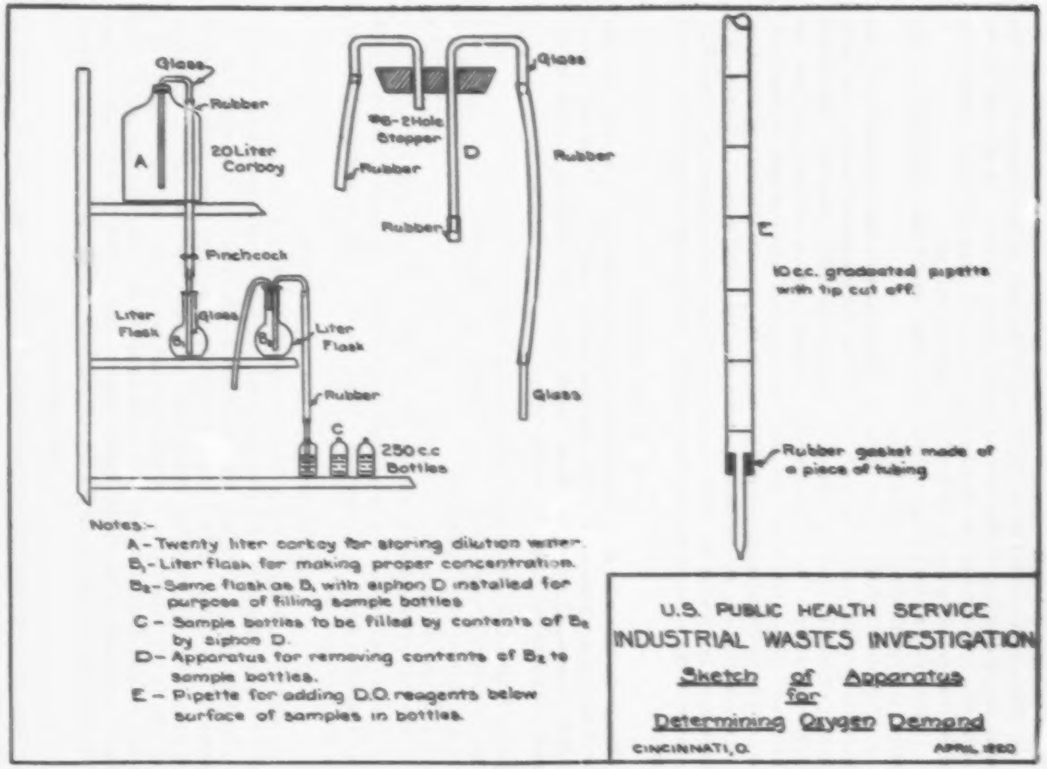
(*b*) A stock solution is prepared of the desired concentration and the incubation bottles are filled with it, using a siphon. Thus to prepare a 10 per cent concentration, a liter flask is partly filled with the diluting water, 100 c. c. of the sample is added and the liter flask is filled to the mark with the diluting water, moving the siphon up and down to secure good mixing. The contents of the flask are then transferred to incubation bottles, using a small siphon, the first portion going over being rejected in order to clean out the siphon. The three bottles are first filled half full and then nearly to overflowing. Stoppers or tubes are then placed in the bottles, which are then ready for incubation or for the determination of the initial dissolved oxygen content. (See fig. 37.)

If several concentrations of the same waste are to be incubated together, it is convenient to put up one stronger than actually desired and to prepare the others from it. This procedure lessens the sampling error, especially if the concentrations to be put up are small. Thus if it is desired to incubate 1.0, 0.5, 0.25, and 0.125 per cent concentrations, 25 c.c. of the waste are made up to 500 c.c. with precautions as above. The required concentrations may then be obtained by making up to 1 liter 200, 100, 50, and 25 c.c. portions of the 5 per cent concentration in the 500 c.c. flask. The mixture in the 500 c.c. flask may be made more uniform by blowing back the first 50 or 100 c.c. pipetted.

In all the manipulations the siphons and pipettes are kept below the surface of the liquid, not so much to avoid reaeration as to prevent the mechanical entrainment of air bubbles.

In general, the diluting water, prepared as above, will still have a measurable oxygen demand after storage. To determine its magnitude bottles of the same size as those used for the dilutions are filled in the manner described above with the diluting water, rinsing the siphon before use to avoid contamination. These blanks are incubated along with the samples.

Bottles used for incubation tests should be cleaned with concentrated sulphuric acid (or cleaning mixture) followed by thorough rinsing with tap water. Unless this precaution is taken, the values found for the blanks will be misleading.


Glass
Rubber
A
20 Liter Carboy
Pinchcock
Liter Flask
Glass
B_1
B_2
Liter Flask
Rubber
C
250 c.c Bottles
#8-2 Hole Stopper
Rubber
D
Rubber
Glass
Rubber
Rubber
Glass
E
10 c.c. graduated pipette with tip cut off.
Rubber gasket made of a piece of tubing

Notes:-

A - Twenty liter carboy for storing dilution water.

B_1 - Liter flask for making proper concentration.

B_2 - Same flask as B_1 with siphon D installed for purpose of filling sample bottles

C - Sample bottles to be filled by contents of B_2 by siphon D.

D - Apparatus for removing contents of B_2 to sample bottles.

E - Pipette for adding D.O. reagents below surface of samples in bottles.

U.S. PUBLIC HEALTH SERVICE
INDUSTRIAL WASTES INVESTIGATION
Sketch of Apparatus for
Determining Oxygen Demand
CINCINNATI, O. APRIL 1920

FIG. 37.

DETERMINATION OF THE INITIAL OXYGEN CONTENT.

The initial dissolved oxygen content of the diluting water must be determined in all cases. The initial oxygen content of the diluted wastes may be computed from the amount of waste added. If determined analytically, the three following cases should be borne in mind:

(*a*) The oxygen content found analytically is the same as that computed, i. e., the waste has no dissolved oxygen and no initial oxygen demand. In this case, if the initial oxygen content of the diluting water is 8.0, the dissolved oxygen content of a 10 per cent concentration is, obviously, 7.2 parts per million.

(*b*) The dilution shows a higher dissolved oxygen content than computed, i. e., the waste has some dissolved oxygen in it.

(*c*) The dilution shows a lower dissolved oxygen content than computed, i. e. the waste has an initial oxygen demand. In this case the computed value is to be used, since it represents what was actually present at the start of the test. The initial oxygen demand may be determined on a separate portion and deducted from the indicated biochemical oxygen demand. An apparent initial oxygen demand may be found if the Rideal modification is not used in the presence of much organic matter.

If several dilutions are put up at the same time, the initial oxygen content of one is determined and that of the others computed. If the concentrations are all less than 1 per cent, the value for the diluting water may be assumed as that for the diluted sample.

INITIAL OXYGEN DEMAND.

The bottle chosen for this determination is allowed to stand for 10 minutes or longer until this purely chemical part of the reaction has been satisfied. Its oxygen content is then determined, using the Rideal modification. The following illustration will make the method of computing results clear:

	P. p. m.
Initial dissolved oxygen content of the diluting water	8.0
Computed initial oxygen content of a 10 per cent concentration	7.2
Oxygen content found analytically	6.6
Initial oxygen demand of a 10 per cent concentration	0.6
Initial oxygen demand of the waste is (0.6) by (10)	6.0

In most cases the initial oxygen demand is negligible in comparison with the 5 or 10 day demand and may be disregarded. It may, however, form a considerable portion of the 1-day demand.

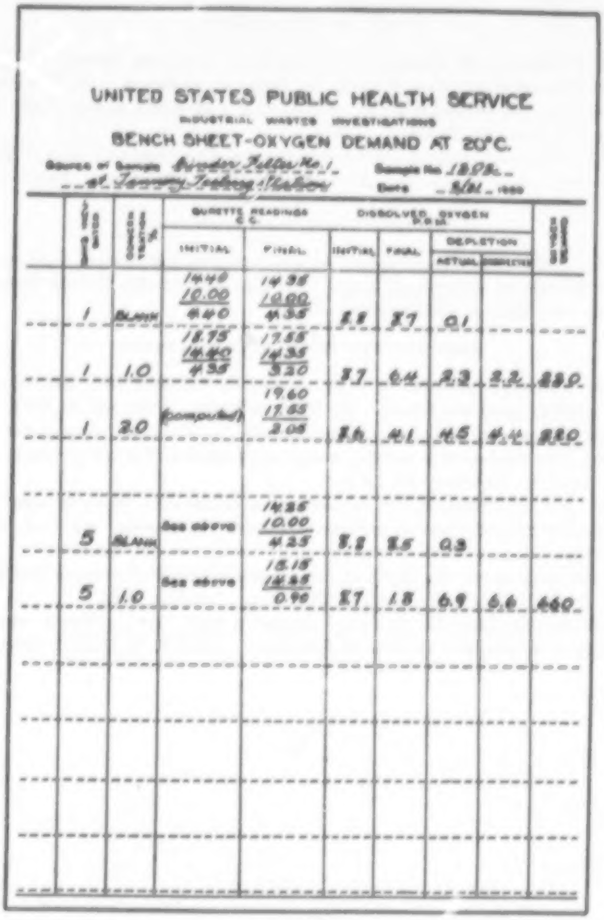
PERIOD OF INCUBATION TO BE CHOSEN.

A 10-day incubation period is taken as a practical limit for the duration of a test. The 10-day oxygen demand is 90 per cent of the 20-day or ultimate oxygen demand. It has been shown, however, that the period of incubation in most cases may be restricted to five days without any great sacrifice in accuracy, and this is the period recommended. To obtain the 10-day oxygen demand, the 5-day value is multiplied by 1.33, or the value found is simply reported as the 5-day oxygen demand. The 1-day oxygen demand value is not representative and may be misleading. The reader is referred to the Public Health Reports, May 7, 1920, for a discussion of the relations existing between oxygen demand values over different periods of incubation.

COMPUTATIONS.

Given the initial and final oxygen content of a diluted sample over any period of time, the oxygen demand of the sample over that time is the corrected difference times a factor for the concentration used. The concentration factor is the reciprocal of the concentration when expressed decimally. Thus, for a 5 per cent concentration, or decimally expressed 0.05, the factor is 20.

The correction is based on the fact that the diluting water itself generally has an appreciable oxygen demand, and is determined by incubating the water under the same conditions as the diluted sample. The correction should be calculated for the amount of diluting water present. If the concentration is 50 per cent, the correction applied should be one-half the value found for the diluting water. If the concentrations are less than 10 per cent, the correction is considered equal to the biochemical oxygen demand of the diluting water and the same for all concentrations. The following bench sheet will make clear the method of computing oxygen demand values from analytical results.



UNITED STATES PUBLIC HEALTH SERVICE
INDUSTRIAL WASTES INVESTIGATIONS
BENCH SHEET-OXYGEN DEMAND AT 20°C.

Source of Sample [illegible] Filter No. 1 at [illegible] Station
Sample No. 1898
Date 8/21 1920

			BURETTE READINGS C.C.		DISSOLVED OXYGEN P.P.M.				
	[illegible]	[illegible] %	INITIAL	FINAL	INITIAL	FINAL	DEPLETION		[illegible]
							ACTUAL	CORRECTED	
	1	BLANK	14.40 10.00 4.40	14.35 10.00 4.35	8.8	8.7	0.1		
	1	1.0	18.75 14.40 4.35	17.55 14.35 3.20	8.7	6.4	2.3	2.2	220
	1	2.0	(computed)	19.60 17.55 2.05	8.6	4.1	4.5	4.4	220
	5	BLANK	See above	14.25 10.00 4.25	8.8	8.5	0.3		
	5	1.0	See above	15.15 14.25 0.90	8.7	1.8	6.9	6.6	660

FIG. 39.

The above directions have been compiled from methods in use by the Public Health Service and from material contained in Public Health Reprint No. 594. Copies of the reprint may be obtained from the Superintendent of Documents, Washington, D. C., and the reader is referred to this publication for further information.

12. *Sludge analyses.*—The procedures given in Standard Methods were followed quite closely. In view of the possible importance of sludge as a fertilizer, rather complete analyses were made of the sludge ash.

RELATED PUBLICATIONS.

Available reprints and bulletins on sewage disposal issued by the Public Health Service, from which copies may be obtained without cost:

PUBLIC HEALTH BULLETINS.

No. 97. Studies on the treatment and disposal of industrial wastes: I. The treatment and disposal of strawboard waste, by Harry B. Hommon. II. The determination of biochemical oxygen demand of industrial wastes and sewage. By Emery J. Theriault and Harry B. Hommon. 1918.

No. 101. Studies of methods for the treatment and disposal of sewage. Treatment of sewage from single houses and small communities. By Leslie C. Frank and C. P. Rhynus. 1919.

HYGIENIC LABORATORY BULLETIN.

No. 89. Sewage pollution of interstate and international waters, with special reference to the spread of typhoid fever. VI. The Missouri River from Sioux City to its mouth. By Allan J. McLaughlin. 1913.

REPRINTS FROM PUBLIC HEALTH REPORTS.

No. 168. The water supplies of ships. Water for drinking amd method of sewage disposal on ships on inland waters. By Hugh de Valin. February 13, 1914.

No. 362. The sewage pollution of streams. By W. H. Frost. September 15, 1916.

No. 504. The treatment of sewage from single houses and small communities. By Earle B. Phelps. February 14, 1919.

No. 594. A further study of the excess oxygen method for the determination of the biochemical oxygen demand of sewages and industrial wastes. By E. J. Theriault. May 7, 1920.

The determination of the biochemical oxygen demand of sewages and industrial wastes. By E. J. Theriault and H. B. Hommon. October, 1918.

No. 625. Sanitary disposal of sewage through a septic tank. Simple construction and inexpensive operation for isolated dwellings. By H. R. Crohurst. December 10, 1920.